53D CONGRESS, 2d Session. | HOUSE OF REPRESENTATIVES. | MIS. DOC. 184, Part 1.

ANNUAL REPORT

OF THE

BOARD OF REGENTS

OF THE

SMITHSONIAN INSTITUTION,

SHOWING

THE OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION

TO

JULY, 1893.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1894.

FIFTY-THIRD CONGRESS, SECOND SESSION.

Concurrent resolution adopted by the Senate January 17, 1894, and by the House of Representatives January 18, 1894.

Resolved by the Senate (the House of Representatives concurring), That there be printed of the Report of the Smithsonian Institution and of the National Museum for the year ending June 30, 1893, in two octavo volumes, 10,000 copies, of which 1,000 copies shall be for the use of the Senate, 2,000 copies for the use of the House of Representatives, 5,000 copies for the use of the Smithsonian Institution, and 2,000 copies for the use of the National Museum.

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

ACCOMPANYING

The annual report of the Board of Regents of the Institution for the year ending June 30, 1893.

SMITHSONIAN INSTITUTION,
Washington, D. C., July 1, 1893.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1893.

I have the honor to be, very respectfully, your obedient servant,

S. P. LANGLEY,
Secretary of Smithsonian Institution.

Hon. ADLAI E. STEVENSON,
President of the Senate.

Hon. CHARLES F. CRISP,
Speaker of the House of Representatives.

ANNUAL REPORT OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1893.

SUBJECTS.

1. Proceedings of the Board of Regents for the session of January, 1893.

2. Report of the Executive Committee, exhibiting the financial affairs of the Institution, including a statement of the Smithson fund, and receipts and expenditures for the year ending June 30, 1893.

3. Annual report of the Secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1893, with statistics of exchanges, etc.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1893.

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REPORT OF THE SECRETARY.

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THE SMITHSONIAN INSTITUTION.

MEMBERS EX OFFICIO OF THE "ESTABLISHMENT."

(January, 1893.)*

BENJAMIN HARRISON, President of the United States.
LEVI P. MORTON, Vice-President of the United States.
MELVILLE W. FULLER, Chief-Justice of the United States.
JOHN W. FOSTER, Secretary of State.
CHARLES FOSTER, Secretary of the Treasury.
STEPHEN B. ELKINS, Secretary of War.
BENJAMIN F. TRACY, Secretary of the Navy.
JOHN WANAMAKER, Postmaster-General.
WILLIAM H. H. MILLER, Attorney-General.
WILLIAM E. SIMONDS, Commissioner of Patents.

*A change of administration took place March 4, 1893

REGENTS OF THE INSTITUTION.

(List given on the following page.)

OFFICERS OF THE INSTITUTION.

SAMUEL P. LANGLEY, *Secretary.*

Director of the Institution and of the U. S. National Museum.

G. BROWN GOODE, *Assistant Secretary.*

REGENTS OF THE SMITHSONIAN INSTITUTION.

By the organizing act approved August 10, 1846 (Revised Statutes, Title LXXIII, section 5580), "The business of the Institution shall be conducted at the city of Washington by a Board of Regents, named the Regents of the Smithsonian Institution, to be composed of the Vice-President, the Chief-Justice of the United States [and the Governor of the District of Columbia], three members of the Senate, and three members of the House of Representatives, together with six other persons, other than members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of the same State."

REGENTS FOR THE YEAR 1893.

The Chief-Justice of the United States:
MELVILLE W. FULLER, elected Chancellor and President of the Board January 9, 1889.

The Vice-President of the United States:
LEVI P. MORTON.

United States Senators:	Term expires.
JUSTIN S. MORRILL (appointed Feb. 21, 1883, and Dec. 15, 1891)	Mar. 3, 1897.
SHELBY M. CULLOM (appointed Mar. 23, 1885, and Mar. 28, 1889)	Mar. 3, 1895.
GEORGE GRAY (appointed Dec. 20, 1892, and Mar. 16, 1893)	Mar. 3, 1899.
Members of the House of Representatives:	
JOSEPH WHEELER (appointed Jan. 5, 1888, and Jan. 15, 1892)	Dec. 27, 1893.
HENRY CABOT LODGE (appointed January 15, 1892)	Dec. 27, 1893.
W. C. P. BRECKINRIDGE (appointed January 15, 1892)	Dec. 27, 1893.
Citizens of a State:	
HENRY COPPÉE, of Pennsylvania (first appointed Jan. 19. 1874)	Jan. 26, 1898.
JAMES B. ANGELL, of Michigan (appointed Jan. 19, 1887, reappointed Jan. 9, 1893)	Jan. 19, 1899.
ANDREW D. WHITE, of New York (first appointed Feb. 15, 1888)	Feb. 15, 1894.
WILLIAM P. JOHNSTON, of Louisiana (appointed Jan. 26, 1892)	Jan. 26, 1898.
Citizens of Washington:	
JAMES C. WELLING (first appointed May 13, 1884)	May 22, 1896.
JOHN B. HENDERSON (appointed January 26, 1892)	Jan. 26, 1898.

Executive Committee of the Board of Regents.

JAMES C. WELLING, *Chairman.* HENRY COPPÉE. J. B. HENDERSON.

JOURNAL OF PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION.

ANNUAL MEETING OF THE BOARD OF REGENTS.

JANUARY 25, 1893.

The annual meeting of the Board of Regents of the Smithsonian Institution was held to-day at 10 a. m. Present: The chancellor, Mr. Chief Justice Fuller; Vice-President L. P. Morton; the Hon. J. S. Morrill; the Hon. S. M. Cullom; the Hon. George Gray; the Hon. Joseph Wheeler; the Hon. Henry Cabot Lodge; the Hon. W. C. P. Breckinridge; Dr. J. C. Welling; Dr. Henry Coppée; Dr. William Preston Johnston; John B. Henderson, esq., and the secretary.

A letter was read from Dr. J. B. Angell, stating that his nonattendance was on account of important business engagements.

The secretary then presented the minutes of the last annual meeting of January 27, 1892, and of the special meeting of March 29, 1892, which, at the suggestion of the chancellor, he read in abstract. Referring to the mention there of authority given by the Regents at the last regular meeting to bring the matter of an additional appropriation for administrative expenses before Congress, the secretary remarked that the time had not been considered opportune and that the Regents' authorization had not yet been acted upon.

The minutes of both meetings were approved.

The secretary then announced that the Vice-President, on December 20, 1892, appointed as Regent the Hon. George Gray, a U. S. Senator, in place of the Hon. R. L. Gibson, deceased. Also that by joint resolution, approved by the President January 9, 1893, Dr. J. B. Angell had been reappointed a Regent to succeed himself, his term expiring January 19, 1893.

The secretary announced the death of the Hon. R. L. Gibson on December 15, 1892, remarking that one who had known him longer and better than he had, would doubtless say what was fitting in this connection.

Dr. Johnston then moved that a committee be appointed to draft a suitable memorial and resolutions, which was carried, and the chancellor appointed Dr. Johnston, Senator Morrill, and the secretary a com-

mittee of three to report the resolutions to the board. Dr. Johnston then presented the following memorial and resolutions, which were adopted:

THE BOARD OF REGENTS:

Your committee report that the Hon. Randall Lee Gibson was appointed a Regent of the Smithsonian Institution December 19, 1887, and filled that office until his death, December 15, 1892.

Senator Gibson brought to the performance of his duties as Regent a rare preparation as student, scholar, and statesman. With inherited talents for oratory and with strong literary tendencies, he was surrounded in youth by all the influences that direct the energies of man to the public welfare. At Yale College he took a very prominent stand in a group noted for talents and enthusiasm. Foreign travel, the study of the law, the life of a planter, a distinguished military career, and long service in the Congress of the United States filled his capacious mind with a store of a rich and varied experience and trained him for the highest duties. Life was to him a consecration to public duty, and the performance of that duty his highest felicity. Benevolent, brave, patient, prudent, faithful, his grace and gentleness were the rich drapery of an inflexible will and tenacious purpose.

He came to the Smithsonion Institution as a servant animated by the fullest sense of his responsibilities and self-pledged to a rigid performance of them. His interest in the institution has been limited only by the conditions of his position. His death is a loss to his State and his country, in whose councils he has served for eighteen years.

In view of these facts, it is—

Resolved, That in the death of the Hon. Randall Lee Gibson the Smithsonian Institution has lost a zealous and useful regent, and its board a valued member whose services can ill be spared.

Resolved, That we lament his loss as an acceptable colleague, a gracious gentleman, a patriotic citizen, and a wise statesman, whose interest in the spread of knowledge among men fitted him well for his duties on this board.

Resolved, That these resolutions be entered on the minutes of the board and a copy be transmitted to the family of our friend.

Dr. Johnston added that Senator Gibson's death was a particular sorrow to him; they had been friends from boyhood with never a single cloud in their friendship. He was with Senator Gibson in his last hours and felt in his death a great personal loss, and he did not doubt that all who knew him personally regretted his loss to themselves and to the country.

The secretary then announced the death on March 4, 1892, of Dr. Noah Porter, a former Regent.

The secretary presented his report for the year ending June 30, 1892, stating that it was confined to matters of major importance, matters of detail being found in the appendix. He had endeavored to put into it only matters that might demand publicity, and had arranged the report in this form so as to permit it to be read. He had dwelt at some length on the features of the National Zoological Park. The rest of the report would speak for itself, but he might call attention to statements about the disposition of the income of that portion of Mr. Hodgkin's gift which was specially directed to one purpose, and to the form of some of the letters written to distinguished men all over the world in relation to it.

The report was accepted.

Dr. Welling, on behalf of his colleagues, presented the report of the executive committee to June 30, 1892, which was adopted.

Dr. Welling also said that he would here present the usual resolution relative to the income and expenditures of the institution, which was adopted, as follows:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1894, be appropriated for the service of the institution, to be expended by the Secretary with the advice of the executive committee, upon the basis of the operations described in the last annual report of said committee, with full discretion on the part of the secretary as to items of expenditures properly falling under each of the heads embraced in the established conduct of the institution.

Dr. Welling then said that at the last regular meeting, the secretary had presented a statement of the burdens imposed by the need of his personally signing all purely routine money papers, and the board had referred a resolution on the subject to the executive committee, with power to act. He would now present the result of their action as follows:

WASHINGTON, D. C., *April 15, 1892.*

Whereas a member of the Board of Regents, at their last meeting on January 27, 1892, offered the following resolution:

"*Resolved,* That the Secretary be empowered to appoint some suitable person who, in case of need, may sign such requisitions, vouchers, abstracts of vouchers, accounts current, and indorsements of checks and drafts, as are needed in the current business of the Institution or of any of its bureaus, and are customarily signed in the bureaus of other Departments of the Government."

And whereas this was referred to the executive committee with power to act—

Resolved, That the executive committee approve the resolution in the terms proposed, and confirm the Secretary in the powers therein mentioned.

JAMES C. WELLING,
HENRY COPPÉE,
J. B. HENDERSON,
Executive Committee.

Dr. Welling added that the action was taken simply to relieve the Secretary of what was becoming a too heavy tax upon his time and in other ways an increasing burden, and it was to further provide that, in case of his absence, the work of the Institution should not be suspended; that he had now power to delegate authority to sign such routine papers.

The Secretary announced the death of Mr. Thomas G. Hodgkins on November 25, 1892, and read the following obituary notice:

Mr. Thomas G. Hodgkins, who died at Setauket, Long Island, on November 25, 1892, was born in London, England, in 1803. His ancestors were clergymen, and belonged to the class of English gentlemen, but his father, who was in reduced circumstances, was unable to keep him at Eton or Harrow, and sent him to France, where he remained for his education until he was about 15 years old. During this time his language, habits, and manners became rather French than English.

He returned to England, but troubles with a stepmother made his home unbearable, and against the urgent entreaty of his father he shipped before the mast in a trading vessel bound for Calcutta. The vessel was wrecked near the mouth of the

Hoogly, and young Hodgkins found himself penniless and friendless in Calcutta, where he was taken ill and carried to the hospital. He has since said that it was here, and when he was a sick lad, who was told that he had not six months to live, that he made up his mind that he would live, that he would acquire a fortune, and that he would devote it to large and philanthropic ends.

He recovered sufficiently to prepare a petition to the Governor-General of India, who was then the Marquis of Hastings, asking for aid to return to England; and he walked a long distance into the country, where the Governor-General was staying at his country seat, to deliver it. He arrived at the vice-regal residence bare footed and ill-clad, and asked an audience with the ruler of India with such persistence that the attendants, who at first refused, finally consented to present his petition. This so impressed the viceroy when he read it that he directed that the young sailor should be admitted to see him, and the interview that followed ended by his offering young Hodgkins a position in his household which any gentleman's son might have been willing to accept, but which he refused from his overmastering wish to return to his father.

I think this curious adventure (as it may almost be called) deserves narration as an instance both of the remarkable force of Mr. Hodgkins's character and of the evidence of gentle breeding his manners always bore, and of the influence both had on others even in his earliest years.

After going home he went to Spain, and later, returning to England, he married, and in 1830 came to this country. He immediately engaged in business, which he pursued with unremitting energy for thirty years, when he retired on what was at that time considered a handsome fortune. The fifteen years following this he spent in travelling over Europe and America, and in 1875 he settled down in Setauket, Long Island, upon his place "Brambletye Farm," which he rarely left, except for an occasional visit to New York, until his death.

Mr. Hodgkins was a man of remarkably self-poised mind, singularly independent in his modes of thought, and independent also of the need of social converse or of adventitious interests. His opinions were his own, and he found in the reading which confirmed them and in the care of his little farm abundant and agreeable occupation for his declining years. He was a man of keen intelligence, and by nature, perhaps, still more a thinker and a scholar than a man of affairs, though even in the latter capacity his ability was proven by his success in business. He possessed a strong will, and had deliberately formed and tenaciously held opinions of his own in relation to religious and philosophical questions. In regard to the former, it may be sufficient to say that his mind was of a devout cast, and that while he had thought much for himself, he retained to the last an absolute trust in the divine guidance as the leading motive of his life.

Mr. Hodgkins had for more than thirty years made a special study of the atmosphere in its relations to the well-being of humanity. He believed that most of the physical evils to which mankind are subject arise from the vitiation of the air which they breathe, and that the study of the atmosphere is not unimportant even with relation to man's moral and spiritual, as well as his physical health; and though he did not point out any line of investigation likely to bear fruit in the latter direction, it was his hope that the concentration of thought upon the atmosphere and its study from every point of view, would in time lead to results which would justify his almost devout interest in the subject.

In this last respect, his beliefs about the atmosphere, otherwise clear enough, were not always easy to follow, but though all those who talked to him were not sure that they here understood his full meaning, it was at least plain that he was well content to place his trust in the charge of such an institution as the Smithsonian, and to leave it to the future to shape the result.

He was very explicit, however, in his statements that it was not for sanitary science or for meteorology, or for the like branches of study alone or for those which

might seem most obviously suggested by the words of his trust, to profit exclusively by it, for he believed that every department of philosophy (using the term in its widest sense) would be found to be finally connected with every other, through this common bond of union; so that it was his particular desire to have such varied investigations in the atmosphere made as would aid in the knowledge of each and all of these aspects of knowledge.

Mr. Hodgkins brought to all his studies, as to this, a very retentive memory, while general reading and travel had stored his mind with singularly varied information. He was a good French scholar and loved to quote from the French classics. His catholicity of mind was sufficient to include a not inconsiderable sense of humor, and his favorite quotation from Boileau pointed to his consciousness of a perhaps too imaginative indulgence in his favorite themes. He was a punctilious correspondent, and what it is not too much to call his real literary ability, was never shown more happily than in his letters, which were in many respects models of epistolary ease, and even of charm, of diction. He was hospitable and enjoyed entertaining the few friends whom he admitted to his table, where his manner, as a host of the old school, was a happy one.

Mr. Hodgkins had no family and no known blood relations, and, recognizing the difficulties which often arise over the settlements of large estates, he chose to be his own executor rather than leave the disposition of his affairs to those who might either misinterpret or disregard his requests when he could no longer appear as a witness in his own behalf. He therefore gave away his entire estate, amounting to about half a million dollars, to various public institutions.

His funeral was unostentatious, as he requested it should be, only his intimate friends attending. Among these he (the Secretary) was numbered; for while he felt it his official duty to represent this Institution at the funeral of one to whom it owed so much, he desires to say, in concluding this brief notice, that he was there also from a feeling of real friendship and regard to an old man whose singular powers, whose lonely life, and whose perhaps often unmet affection had drawn the speaker to him as to a personal friend.

Mr. Wheeler remarked that the gentleman who had given the Institution so much deserved some special record of his death, and he moved that the notice should be extended by the Secretary, should include a statement of the gifts he had made, and should be spread upon the records of the Board. The motion was carried.

The Secretary then presented the portrait of Mr. Hodgkins, which he stated he had wished to order under the instructions of the Board during Mr. Hodgkins's lifetime, but owing to that gentleman's reluctance to be portrayed, it was not executed until after his death, and from a photograph. It was not yet finished, the artist, Mr. Robert Gordon Hardie, desiring its return in order that he might elaborate it.

The Secretary added that from his knowledge of the original he considered, and that the assistant secretary Dr. Goode (who was well qualified to judge), also considered the picture a very satisfactory likeness indeed. Dr. Welling remarked that it looked as if it could hardly be much improved as a likeness by much greater elaboration. Mr. Lodge said that while he could not, of course, speak of the likeness in case of one he had not seen, the picture bore its own evidence that it was a piece of good work. Other commendatory remarks were made.

The secretary called the attention of the Regents to the action taken with regard to that portion of the Hodgkins fund which was especially

devoted to scientific purposes. He had taken counsel with many eminent scientific men in Europe as well as at home, as to the best disposition to make of this fund, and given the matter much thought. A portion of the results of this care was embodied in the circular which he then presented for the consideration of the board.

He stated that it was the intention to send this circular to all parts of the world, and that after eliminating from the list of the correspondents of the institution, those which it was not considered should receive it—about two-thirds in all—there yet remained about 8,000 to be supplied; and these were scattered all over the inhabited parts of the globe, including Africa, and the small islands of the Pacific.

In affixing the old seal of the institution to these, the secretary had noticed that it bore no legend or indication of the institution's purposes, although to the vast majority of those receiving it, these were unknown. He had been led by this to prepare a new seal in which the words of Smithson, "For the increase and diffusion of knowledge among men" should take the place of his face. He would speak of this later.

The circular was examined by the members of the board. The chancellor said it might be well to state on the heading of the circular that the President of the United States was *ex-officio* presiding officer of the institution, and the secretary stated that he would act on the suggestion.

After reading the circular in brief, the secretary recurred to the subject of the seal. He said he had consulted a number of sources for such a design, without much success, until he had finally been fortunate in securing one from Mr. St. Gaudens, who had made one from the secretary's indications, which he was glad to submit to the regents.

The Secretary remarked that the preparation of the circular and the announcement of the prizes and medal had been made under the instructions of the board that this portion of the income should be expended in carrying out the express wishes of the donor. The circular had been carried down to Setauket and was one of the last things that had occupied the attention of Mr. Hodgkins. He was personally consulted about it and approved the plan.

Mr. Lodge then offered the following resolution, which was adopted:

Resolved, That the Secretary be authorized to procure a new seal for the institution, with a suitable motto and device, to comprehend the words of Smithson, "For the increase and diffusion of knowledge among men," and also the words, "Smithsonian Institution, Washington, 1846."

The Secretary then read a portion of the will of Mr. Hodgkins where he makes the institution his residuary legatee. He wished to state that he had learned from the executor, but altogether unofficially, that the amount coming to the institution under this will, as residuary legatee, was but a few thousand dollars, Mr. Hodgkins having meant to give away as far as possible all of his property at the time of his death. He

also stated that it was, however, probable that certain bonds deposited by Mr. Hodgkins in a trust company, though forming no portion of the residuary estate, would come to the institution, and he asked the instructions of the Regents as to their disposition.

Dr. Welling then read the following resolution:

Resolved, That the Secretary be authorized to sell at the market price, any bonds or securities which may accrue to the institution as residuary legatee of the late Thomas G. Hodgkins, or from any trust instituted by him in its favor, if it is in the Secretary's judgment desirable to do so; and should there accrue any further sum not demanding the special consideration of the Regents by its importance, that he be authorized to apply it to the general purposes of the institution.

On motion of Senator Cullom, the resolution was adopted.

The Secretary then brought before the board the matter of the change in the organization of the establishment, calling attention to two points for consideration:

At a meeting of the Regents on January 28, 1891, the Secretary stated that he had been authorized by the President, the Vice-President, the Chief-Justice, and other members of the establishment to ask for legislation to make the establishment consist of the President, Vice-President, Chief-Justice, and all the heads of Departments.

Since the Institution was established the place filled by the Commissioner of Patents would seem to have been taken by the creation of the Secretary of the Interior. The Secretary of Agriculture has been created, while the office of the governor of the District of Columbia no longer exists.

The proposed change would be covered by the following act:

Be it enacted, etc., That "An act to establish the Smithsonian Institution for the increase and diffusion of knowledge among men," approved August 10, 1846, Revised Statutes, Title LXXIII, be, and the same is hereby, amended in Section 5579 of said act by striking out the words "the Secretary of State, the Secretary of the Treasury, the Secretary of War, the Secretary of the Navy, the Postmaster-General, the Attorney-General, the Commissioner of the Patent-Office, and the governor of the District of Columbia, and such other persons as they may elect honorary members," and inserting the words "the heads of Executive Departments," so that the section will read:

"SEC. 5579. The President, the Vice-President, the Chief-Justice, and the heads of Executive Departments are hereby constituted an establishment by the name of the 'Smithsonian Institution' for the increase and diffusion of knowledge among men; and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions hereinafter contained, and no other."

The Secretary said that he had consulted the President, the Vice-President, the Chief Justice, the Secretary of State, and those two members of the Cabinet mostly interested, and had their sanction in making this suggestion, and though it was a matter which concerns the establishment, he thought it proper to state his proposed action to the Regents, and if there were no objection on their part, he would infer their assent to this the first amendment sought.

The second change proposed by the Secretary, after consultation with the Chief Justice, and after an examination of the fundamental act by Mr. H. E. Davis, was as follows:

To amend Section 5591 of the Revised Statutes by the addition of these words:

But this shall not operate as a limitation on the power of the Smithsonian Institution to receive money or other property by gift, bequest, or devise, and to hold and dispose of the same in promotion of the purposes thereof, and as provided in the next section.

The chancellor said, with regard to legislation concerning the funds, that section 5591 might possibly as it stood appear to operate as a limitation; and that, though he did not himself consider that any reasonable doubt could arise as to the right of the Regents to hold property outside of the million any more than to deposit sums within it, yet, out of abundant precaution, he had approved of the addition of the words as read.

A motion by Senator Morrill that the Secretary be authorized to draw up a bill providing for such changes in the legislation as were desirable in sections 5579 and 5591 of the Revised Statutes, and to present the same to the Senate and House through Congressional Regents, was then put by the chancellor and carried.

There being no further business to come before the board, on motion it adjourned.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDING JUNE 30, 1893.

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Institution, the appropriations by Congress, and the receipts and expenditures for the Smithsonian Institution, the U. S. National Museum, the International Exchanges, the Bureau of Ethnology, the National Zoological Park, and the Astro-Physical Observatory for the year ending 30th June, 1893, and balances of former years:

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1893.

The amount of the bequest of James Smithson deposited in the Treasury of the United States, according to the act of Congress of August 10, 1846, was $515,169. To this was added, by authority of Congress, February 8, 1867, the residuary legacy of Smithson, savings from income and other sources, to the amount of $134,831.

To this also have been added a bequest from James Hamilton, of Pennsylvania, of $1,000; a bequest of Dr. Simeon Habel, of New York, of $500; the proceeds of the sale of Virginia bonds, $51,500, and a gift from Thomas G. Hodgkins, of New York, of $200,000, making in all, as the permanent fund, $903,000.

Statement of the receipts and expenditures from July 1, 1892, to June 30, 1893.

RECEIPTS.

Cash on hand July 1, 1892		$47, 875. 33	
Interest on fund July 1, 1892	$27, 090. 00		
Interest on fund January 1, 1893	27, 090. 00		
		54, 180. 00	
			$102, 055. 33
Cash from sales of publications		556. 58	
Cash from repayments, freight, etc		3, 235. 96	
			3, 792. 54
Total receipts			105, 847. 87

EXPENDITURES.

Building:			
Repairs, care, and improvements	$2,609.94		
Furniture and fixtures	688.18		
		$3,298.12	
General expenses:			
Meetings	492.00		
Postage and telegraph	356.18		
Stationery	628.08		
General printing	279.83		
Incidentals (fuel, gas, etc.)	3,793.72		
Library (books, periodicals)	1,655.75		
Salaries *	18,751.92		
		25,957.48	
Publications and researches:			
Smithsonian contributions	2,731.62		
Miscellaneous collections	6,670.64		
Reports	801.60		
Researches	3,010.95		
Apparatus	1,808.56		
Museum	1,045.38		
Hodgkins fund	1,912.13		
		17,980.88	
Literary and scientific exchanges		1,518.57	
			$48,755.05
Balance unexpended June 30, 1893			57,092.82

The cash received from the sale of publications, from repayments for freights, etc., is to be credited to the items of expenditure as follows:

Incidentals		$12.25
Smithsonian contributions	$315.32	
Miscellaneous collections	172.16	
Reports	69.10	
		556.58
Apparatus		148.50
Museum		1,541.22
Exchanges		1,483.99
Services		50.00
		3,792.54

The net expenditures of the Institution for the year ending June 30, 1893, were therefore $44,962.51, or $3,792.54 less than the gross expenditures, $48,755.05, as above stated.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise are deposited with the Treasurer of the United States to the credit of the Secretary of the Institution, and all payments are made by his checks on the Treasurer of the United States.

* In addition to the above $18,751.92 paid for salaries under general expenses $6,719.81 were paid for services, viz, $141.07 charged to apparatus account, $1,500 to building account, $823.87 to library account, $2,854.05 to researches account, and $1,399.92 to Smithsonian contribution accounts.

Your committee also presents the following statements in regard to appropriations and expenditures for objects intrusted by Congress to the care of the Smithsonian Institution:

INTERNATIONAL EXCHANGES.

Receipts.

Appropriated by Congress for the fiscal year ending June 30, 1893, "for the expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employés."

Sundry civil act, August 5, 1892	$12,000.00
Deficiency act, March 3, 1893	5,000.00
	17,000.00

Expenditures from July 1, 1892, to June 30, 1893.

Salaries or compensation: *			
1 curator, 12 months, at $225	$2,700.00		
1 clerk, 12 months, at $160	1,920.00		
1 clerk, 12 months, at $120	1,440.00		
1 clerk, 12 months, at $85	1,020.00		
1 clerk, 12 months, at $80	960.00		
1 clerk, 12 months, at $75	900.00		
1 clerk, 12 months, at $75	900.00		
1 clerk, 12 months, at $65	780.00		
1 clerk, 1½ months, at $45	67.50		
1 clerk, 2 months, at $40, $80; 17 days, at $40, $22.67	102.67		
1 stenographer, 3 months, at $45	135.00		
1 copyist, 1 month, at $40, $40; 15 days, at $40, $19.35	59.35		
1 packer, 5 months, at $75, $375; 7 months, at $50, $350	725.00		
1 packer, 5 months, at $50	250.00		
1 laborer, 5 months, at $35	175.00		
1 laborer, 92 days, at $1.50	138.00		
1 agent, 6 months, at $83.33⅓	500.00		
1 agent, 6 months, at $50	300.00		
Total salaries or compensation		$13,072.52	
General expenses:			
Freight	1,537.57		
Packing boxes	441.40		
Printing and binding	198.60		
Postage	150.00		
Stationery and supplies	337.68		
		2,665.25	
Total expenditure from July 1, 1892, to June 30, 1893			15,737.77
Balance July 1, 1893, to meet outstanding liabilities			1,262.23

* The payments of salaries for parts of months in January, March, July, August, October, and December are made on the basis of 31 days, and for the other months (except February) at 30 days.

NORTH AMERICAN ETHNOLOGY.

Appropriation by Congress for the fiscal year ending June 30, 1893, "for continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employés." (Sundry civil act, August 5, 1892)	$40,000.00
Balance July 1, 1892, as per last annual report	15,008.06
	55,008.06

The actual conduct of these investigations has been continued by the Secretary in the hands of Maj. J. W. Powell, Director of the U. S. Geological Survey.

Expenditures July 1, 1892, to June 30, 1893.

Salaries or compensation:		
1 ethnologist, 12 months, at $250		$3,000.00
1 ethnologist, 7 months, at $250		1,750.00
2 ethnologists, 12 months, at $200		4,800.00
1 ethnologist, 12 months, at $166.66		1,999.92
2 ethnologists, 12 months, at $150		3,600.00
1 ethnologist, 13 months, at $133.33		1,733.29
1 assistant ethnologist, 9 months, at $116.66, $1,049.94; 21 days, at $116.66, $87.49; 14 days, at $116.66, $54.44		1,191.87
1 assistant ethnologist, 2 months, at $100, $200; 10 months, at $116.66, $1,166.60		1,366.60
1 assistant ethnologist, 2½ months, at $75, $187.50; 9½ months, at $100, $950		1,137.50
1 assistant ethnologist, 7½ months, at $60		452.14
1 archæologist, 12 months, at $216.66		2,599.92
1 assistant archæologist, 12 months, at $125		1,500.00
2 assistant archæologists, 12 months, at $100		2,400.00
1 stenographer, 12 months, at $125		1,500.00
1 stenographer, 1 month, at $60		60.00
1 draftsman, 2 months, at $183.33, $366.66; 14 days, at $183.33, $82.79		449.45
1 draftsman, 2 months, at $116.66, $233.32; 14 days, at $116.66, $52.68		286.00
1 clerk, 12 months, at $100		1,200.00
2 clerks, 12 months, at $60		1,440.00
1 copyist, 12 months, at $70		840.00
1 copyist, 2½ months, at $83.33, $208.32; 9½ months, at $100, $950		1,158.32
1 copyist, 12 months, at $50		600.00
1 messenger, 12 months, at $50		600.00
1 laborer, 12 months, at $50		600.00
1 modeler, 12 months, at $60		720.00
Total salaries or compensation		36,985.01
Miscellaneous:		
Traveling expenses	$3,281.36	
Field expenses	311.50	
Drawings	970.25	
Stationery	159.05	
Freight	229.53	
Field material	137.73	
Supplies	1,711.14	

Miscellaneous—Continued.

Publications	$399.36		
Specimens	3.00		
Miscellaneous	310.84		
		$7,513.76	
			$44,498.77
Balance July 1, 1893			10,509.29

Expenditures reclassified by subject-matter:

Sign language and picture writing	$4,408.65	
Exploration of mounds	2,401.80	
Researches in archæology	12,280.59	
Researches, language of North American Indians	13,015.59	
Salaries in office of Director	7,398.32	
Illustrations for reports	2,196.34	
Researches among Pueblos	1,621.77	
Contingent expenses	1,175.71	
Total expenditures North American ethnology		$44,498.77
Balance July 1, 1893		10,509.29

Summary.

July 1, 1892.	Balance on hand	$15,008.06
	Appropriation for North American ethnology	40,000.00
		55,008.06
	Expended	44,498.77
Balance July 1, 1893		10,509.29

NATIONAL MUSEUM.

PRESERVATION OF COLLECTIONS, JULY 1, 1892, TO JUNE 30, 1893.

Receipts.

Appropriation by Congress for the fiscal year ending June 30, 1893, "for continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employés:"

Sundry civil act, August 5, 1892	$132,500.00
Deficiency act, March 3, 1893	2,000.00
	134,500.00

Expenditures.

Salaries or compensation:

DIRECTION.

1 Assistant Secretary of the Smithsonian Institution, in charge of U. S. National Museum, 12 months, at $333.33	$3,999.96

SCIENTIFIC STAFF

1 curator (in charge), 12 months, at $225	$2,700.00
3 curators, 12 months, at $200	7,200.00
1 curator, 12 months, at $175	2,100.00
1 curator, 12 months, at $100	1,200.00

Salaries or compensation—Continued.

1 curator, 6 months, at $150; 6 months, at $155	$1,830.00	
1 curator (acting), 12 months, at $140	1,680.00	
1 assistant curator, 12 months, at $166.66	1,999.92	
1 assistant curator, 10 months 13 days, at $140	1,458.71	
1 assistant curator, 11 months 14 days, at $133.33	1,528.85	
1 assistant curator, 9 months 27 days, at $125; 1 month, at $100	1,335.61	
1 assistant curator, 230 days, at $5	1,150.00	
1 assistant, 12 months, at $80	960.00	
1 assistant, 9 months, at $85	765.00	
1 aid, 12 months, at $100	1,200.00	
1 aid, 12 months, at $80	960.00	
1 aid, 1 month 16 days, at $80	121.29	
1 aid, 2 months 20 days, at $75	200.00	
1 aid, 12 months, at $60	720.00	
1 aid, 15 days, at $60	29.03	
1 aid, 4 months 15 days, at $50	224.19	
1 aid, 1 month, at $50; 25 days, at $50 per month, $40.32; 23 days, at $50 per month, $38.33; 7 days, at $50 per month, $11.29	139.94	
1 aid, 12 months, at $40	480.00	
1 aid, 3 months 8 days, at $40	130.32	
1 aid, 1 month 16 days, at $40	60.65	
1 collector, 3 months 15 days, at $140	487.74	
1 collector 2 months, at $50	100.00	
		$30,761.25

CLERICAL STAFF.

1 chief clerk, 12 months, at $187.50	2,250.00
1 chief of division, 6 months, at $175; 6 months, at $185	2,160.00
1 registrar, 12 months, at $158.33	1,899.96
1 disbursing clerk, 12 months, at $100	1,200.00
1 assistant librarian, 12 months, at $100	1,200.00
1 stenographer, 12 months, at $85	1,020.00
1 stenographer, 5 months 11 days, at $50	267.74
1 clerk, 12 months, at $125	1,500.00
2 clerks, 12 months, at $115	2,760.00
2 clerks, 12 months, at $100	2,400.00
1 clerk, 1 month, at $100	100.00
1 clerk, 12 months, at $90	1,080.00
1 clerk, 12 months, at $83.33	999.96
1 clerk, 6 months 8 days, at $75	469.35
1 clerk, 12 months, at $70	840.00
1 clerk, 9 months, at $70	630.00
1 clerk, 9 months, at $70; 3 months, at $60	810.00
2 clerks, 12 months, at $60	1,440.00
1 clerk, 6 months 16 days, at $60	390.97
1 clerk, 3 months, at $60	180.00
1 clerk, 1 month, at $60	60.00
3 clerks, 12 months, at $55	1,980.00
1 clerk, 11 months 28 days, at $55	654.68
3 clerks, 12 months, at $50	1,800.00
1 clerk, 5 months, at $50	250.00
1 clerk, 3 months, at $50	150.00
1 clerk, 8 days, at $50	12.90

Salaries or compensation—Continued.

1 copyist, 12 months, at $55	$660.00	
2 copyists, 12 months, at $50	1,200.00	
1 copyist, 6 months 26 days, at $50	341.94	
1 copyist, 4 months 28 days, at $50	246.67	
1 copyist, 3 months, at $50	150.00	
1 copyist, 11 months, at $45; 1 month, at $35	530.00	
5 copyists, 12 months, at $40	2,400.00	
1 copyist, 2 months, at $40	80.00	
1 copyist, 1 month 16 days, at $40	60.64	
1 copyist, 12 months, at $35	420.00	
1 copyist, 8 months, at $35	280.00	
1 copyist, 3 months 12 days, at $35; 7 months, at $30	328.55	
1 copyist, 12 months, at $30	360.00	
1 copyist, 11 months 29 days, at $30	359.00	
1 typewriter, 9 months, at $50, $450; 28 days, at $50 per month, $45.16; 26 days, at $50 per month, $43.33; 26 days, at $50 per month, $41.94	580.43	
1 typewriter, 1 month 7 days, at $50; 3 months 24 days, at $30	174.52	
		$36,677.31

PREPARATORS.

1 preparator, 12 months, at $120	1,440.00	
1 preparator, 8 months, at $100 per month, $800; 23 days, at $100 per month, $74.19; 16 days, at $100 per month, $51.61	925.80	
1 preparator, 9 months 16 days, at $80	761.29	
1 preparator, 1 month 16 days, at $75	113.71	
1 preparator, 16 days, at $75 per month	38.71	
1 preparator, 5 months, at $60, $300; 28 days, at $60 per month, $54.19; 28 days, at $60 per month, $54.19; 1 day, at $60 per month, $2.14	410.52	
1 preparator, 4 months 21 days, at $40	190.00	
1 preparator, 1 month 16 days, at $40	60.65	
1 preparator, 1 month, at $21	21.00	
1 artist, 12 months, at $110	1,320.00	
1 photographer, 12 months, at $158.33	1,899.96	
1 taxidermist, 12 months, at $125	1,500.00	
1 taxidermist, 1 month 17 days, at $80	123.87	
1 taxidermist, 12 months, at $60	720.00	
1 taxidermist, 1 month 16 days, at $60	90.97	
1 taxidermist, 1 month 16 days, at $60	90.97	
1 taxidermist, 16 days, at $50 per month, $25.81; 15 days, at $50 per month, $25	50.81	
1 taxidermist, 16 days, at $50 per month	25.81	
1 taxidermist, 1 month 16 days, at $40	60.65	
1 taxidermist, 2,504 hours, at 45 cents	1,126.80	
		10,974.52

BUILDINGS AND LABOR.

1 superintendent, 12 months, at $137.50	1,650.00	
1 assistant superintendent, 2 months, at $100; 10 months, at $90	1,100.00	
3 chiefs of watch, 12 months, at $65	2,340.00	
1 watchman, 12 months, at $65	780.00	

Salaries or compensation—Continued.

7 watchmen, 12 months, at $50	$4,200.00
1 watchman, 10 months, at $50, $500; 30 days, at $50 per month, $48.39; 26 days, at $50 per month, $46.43	594.82
1 watchman, 11 months, at $50, $550; 30 days, at $50 per month, $48.39	598.39
1 watchman, 11 months, at $50	550.00
1 watchman, 11 months 29 days, at $50	598.33
1 watchman, 11 months, at $50, $550; 30 days, at $50 per month, $48.39	598.39
1 watchman, 11 months 16 days, at $50	575.81
3 watchmen, 12 months, at $45	1,620.00
1 watchman, 10 months 29 days, at $45	492.10
1 watchman, 27 days, at $1.75	47.25
1 skilled laborer, 12 months, at $52	624.00
1 skilled laborer, 1 month, at $50	50.00
1 skilled laborer, 8 months, at $45; 26 days, at $2	412.00
3 laborers, 12 months, at $40	1,440.00
1 laborer, 1 month, at $43; 2 months, at $44.50; 6 months at $46; 3 months, at $47.50	550.50
1 laborer, 1 month, at $49.50; 4 months, at $51; 4 months, at $48; 2 months, at $46.50; 1 month, at $45	583.50
1 laborer, 9 months 26 days, at $40; 1 month, at $44.50; 1 month, at $41.50	479.55
1 laborer, 1 month, at $41.50; 10 months 23 days, at $40	471.18
1 laborer, 1 month 16 days, at $60; 55 days, at $1.50	173.47
1 laborer, 1 month 16 days, at $40	60.65
1 laborer, 11 months 24 days, at $40	470.97
1 laborer, 160 days, at $1.50	240.00
1 laborer, 287 days, at $1.50	430.50
1 laborer, 208 days, at $1.50	312.00
1 laborer, 313 days, at $1.50	469.50
1 laborer, 166 days, at $1.50	249.00
1 laborer, 297 days, at $1.50	445.50
1 laborer, 297 days, at $1.50	445.50
1 laborer, 320 days, at $1.50	480.00
1 laborer, 297 days, at $1.50	445.50
1 laborer, 353 days, at $1.50	529.50
1 laborer, 327 days, at $1.50	490.50
1 laborer, 319½ days, at $1.50	479.25
1 laborer, 341½ days, at $1.50	512.25
1 laborer, 319 days, at $1.50	478.50
1 laborer, 150 days, at $1.50	225.00
1 laborer, 86 days, at $1.50	129.00
1 laborer, 10 days, at $1.50	15.00
1 laborer, 9 days, at $1.50	13.50
1 laborer, 40 days, at $1.50	60.00
1 laborer, 7 days, at $1.50	10.50
1 laborer, 2 days, at $1.50	3.00
1 laborer, 44 days, at $1.50	66.00
1 attendant, 12 months, at $40	480.00
1 attendant, 10 months, at $40, $400; 27 days, at $40 per month, $36; 37 days, at $40 per month, $38.71	474.71
2 cleaners, 12 months, at $30	720.00
1 cleaner, 9 months 89½ days, at $30	357.55

Salaries or compensation—Continued.

1 cleaner, 11 months 30½ days, at $30	$359.52	
1 cleaner, 312½ days, at $1	312.50	
1 cleaner, 312 days, at $1	312.00	
1 cleaner, 29 days, at $1	29.00	
1 messenger, 12 months, at $50	600.00	
1 messenger, 12 months, at $45	540.00	
2 messengers, 12 months, at $30	720.00	
2 messengers, 12 months, at $20	480.00	
1 messenger, 1 month, at $25; 6 months, at $20	145.00	
1 messenger, 1 month, at $20; 11 months, at $25	295.00	
1 messenger, 4 months 24 days, at $20	96.00	
1 messenger, 3 months 24 days, at $20	75.48	
1 messenger, 2 months 3 days, at $20; 6 months, at $15	131.94	
1 messenger, 3 months, at $15	45.00	
		$33,764.11
		116,177.15
Special services by job or contract		2,224.83
Total expenditures for services		118,401.98

Summary: Preservation of collections, 1893.

Direction		$3,999.96
Scientific staff		30,761.25
Clerical staff		36,677.31
Preparators		10,974.52
Building and labor		33,764.11
Special or contract work		2,224.83
Total salaries or compensation		118,401.98
Miscellaneous:		
Supplies	$1,888.31	
Stationery	723.25	
Specimens	3,630.02	
Books and periodicals	144.28	
Travel	107.88	
Freight and cartage	1,889.75	
		8,683.49
Total expenditures to June 30, 1893, for preservation of collections, 1893		127,085.47
Balance July 1, 1893, to meet outstanding liabilities		7,414.53

Furniture and fixtures, July 1, 1892, to June 30, 1893.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1893, "for cases, furniture, fixtures, and appliances required for the exhibition and safe-keeping of the collections of the National Museum, including salaries or compensation of all necessary employés." (Sundry civil act, August 5, 1893.)	$15,000.00

EXPENDITURES.

Salaries or compensation—Continued.		
1 engineer of property, 15 days, at $175 per month		$84.68
1 carpenter, 294 days, at $3		882.00
1 carpenter, 234 days, at $3		702.00
1 carpenter, 40 days, at $3		120.00
1 carpenter, 33 days, at $3		99.00
1 carpenter, 21 days, at $3		63.00
1 carpenter, 1 month, at $91		91.00
1 cabinetmaker, 297 days, at $3		891.00
1 painter, 11 months 20 days, at $65 per month		756.94
1 storekeeper, 3 months, at $70		210.00
1 property clerk, 12 months, at $90		1,080.00
1 skilled laborer, 8 months, at $60, $480; 26½ days, at $60 per month, $53; 29 days, at $60 per month, $56.13; 2 months, at $50, $100		689.13
1 skilled laborer, 11 months 15¼ days, at $50		575.00
1 skilled laborer, 1 month 8 days, at $50		67.40
1 skilled laborer, 288 days, at $2		576.00
1 skilled laborer, 61 days, at $2		122.00
1 skilled laborer, 40 days, at $2		80.00
1 skilled laborer, 179 days, at $1.75		313.25
1 laborer, 8 months 29 days, at $40; 2 months, at $41.50		440.42
1 laborer, 1 month 16 days, at $40		60.65
		7,903.47
Special service by job or contract		91.22
Total expenditure for salaries		7,994.69
Miscellaneous:		
Cases	556.53	
Drawings for cases	34.50	
Drawers, trays, boxes	252.60	
Frames, stands, etc.	16.00	
Glass	774.92	
Hardware	649.50	
Tools	25.08	
Cloth, cotton, etc	47.53	
Glass jars	438.10	
Lumber	501.44	
Paints, oils, etc	383.35	
Office furniture	48.22	
Metals	30.89	
Rubber and leather	21.86	
Apparatus	118.20	
Slate, brick, etc	6.50	
Sky-lights	160.00	
		4,065.22
Total expenditure July 1, 1892, to June 30, 1893, for furniture and fixtures, 1893		12,059.91
Balance July 1, 1893, to meet outstanding liabilities		2,940.09

Heating, lighting, electric and telephonic service, July 1, 1892, to June 30, 1893.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1893, "for expenses of heating, lighting, electric, telegraphic, and telephonic service for the National Museum":

(Sundry civil act, August 5, 1892)		$11,000.00
Deficiency act of March 3, 1893)		2,000.00
		13,000.00

EXPENDITURES.

Salaries or compensation:		
1 engineer, 12 months, at $115	$1,380.00	
2 firemen, 12 months, at $50	1,200.00	
1 fireman, 11 months, 12 days, at $50	570.00	
1 telephone clerk, 12 months, at $60	720 00	
1 assistant telephone clerk, 12 months, at $35	420.00	
1 laborer, 1 month, at $45; 5 months, at $40.50; 3 months, at $39; 1 month, at $37.50; 2 months, at $36	474.00	
Special service by job or contract	19.00	
Total expenditure for salaries		$4,783.00
General expenses:		
Coal and wood	$5,003.04	
Gas	1,253.64	
Telephone	730.09	
Electric supplies	67.73	
Rental of call-boxes	100.00	
Heating supplies	222.47	
		7,376.97
Total expenditure July 1, 1892, to June 30, 1893, for heating and lighting, etc., 1893		12,159.97
Balance July 1, 1893, to meet outstanding liabilities		840.03

Postage, July 1, 1892, to June 30, 1893.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1893, "for postage stamps and foreign postal cards for the National Museum" (sundry civil act, August 5, 1892)	$500.00

EXPENDITURES.

City post-office, for postage and postal cards	$500.00

Appropriation all expended July 1, 1893.

Printing, July 1, 1892, to June 30, 1893

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1893, "for the Smithsonian Institution, for printing labels and blanks and for the 'Bulletin' and volumes of the Proceedings of the National Museum" (sundry civil act, August 5, 1892)	$12,000.00

EXPENDITURES.

Bulletins Nos. 40, 43, 44, 45	$2,351.23	
Bulletin No. 39, extras	155.05	
Bulletins, special, Nos. 1 and 2	1,315.70	
Proceedings, vols. 14, 15, 16	2,804.67	
Reports, extras	2,228.40	
Lists, etc	80.18	
Labels for specimens	2,128.82	
Letter heads, pads, and envelopes	268.53	
Blanks	230.05	
Record books	48.22	
Electros	7.00	
Congressional Records	24.00	
Total expenditure		$11,641.85
Balance July 1, 1893		358.15

Building.

Balance July 1, 1892, as per last annual report	$525.36

EXPENDITURES.

From July 1, 1892, to June 30, 1893	$522.53
Balance carried, under the provisions of the Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 3, 1893	2.83

Duties on articles imported for the National Museum.

Balance July 1, 1892, as per last annual report	$58.25
Paid direct by Treasury Department	5.00
Balance carried, under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1893	53.25

Preservation of collections, 1891.

Balance as per last report, July 1, 1892		$291.58
Expenditures to June 30, 1892:		
Specimens	$260.23	
Books	6.03	
Freight	24.28	
Total expenditure		290.54
Balance July 1, 1893, carried under the provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1893		1.04

Preservation of collections, 1892.

Balance as per last report, July 1, 1892			$8,818.14
Expenditures to June 30, 1893:			
Salaries	$440.00		
Special services	330.11		
		$770.11	

Expenditures to June 30, 1893—Continued.

Supplies	$337.50		
Stationery	375.80		
Specimens	6,220.23		
Travel	89.69		
Freight	593.30		
Books	414.46		
		$8,030.98	
Total expenditure to June 30, 1893			$8,801.09
Balance July 1, 1893 to meet outstanding liabilities			17.05

Total expenditures of the appropriation for preservation of collections, 1892.

[Appropriation, $145,000.]

	From July 1, 1891, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total.
Salaries	$122,751.43	$770.11	$123,521.54
Supplies	2,038.76	337.50	2,376.26
Stationery	842.79	375.80	1,218.59
Specimens	6,340.12	6,220.23	12,560.35
Travel	1,574.81	89.69	1,664.50
Freight	2,180.95	593.30	2,774.25
Books	453.00	414.46	867.46
Total	136,181.86	8,801.09	144,982.95
Balance	8,818.14	17.05	17.05

Furniture and fixtures, 1891.

Balance July 1, 1892, as per last annual report $2.35

Carried, under the provisions of the Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1893.

Furniture and fixtures, 1892.

Balance July 1, 1892, as per last annual report		$3,300.37
Expenditures from July 1, 1892, to June 30, 1893:		
Cases	$1,778.00	
Drawers, trays, etc	56.05	
Frames	166.50	
Glass	1,038.14	
Hardware	43.88	
Tools	19.48	
Cloth, etc	8.00	
Glass jars	22.29	
Lumber	47.97	
Office furniture	6.00	
Metals	2.94	
Rubber and leather	13.32	
Apparatus	36.32	
Travel	3.70	
Special service	30.00	
Total expenditure		3,272.59
Balance July 1, 1893, to meet outstanding liabilities		27.78

Total expenditures of the appropriation for furniture and fixtures, 1892.

[Appropriation, $25,000.]

	From July 1, 1891, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total.
Salaries	$13,973.77	$30.00	$14,003.77
Exhibition cases	350.00	1,778.00	2,128.00
Drawings for cases	15.00	....	15.00
Drawers, trays, boxes	543.72	56.05	599.77
Frames, stands, etc	169.50	166.50	336.00
Glass	281.75	1,038.14	1,319.89
Hardware	1,016.95	43.88	1,060.83
Tools	45.59	19.48	65.07
Cloth, cotton, etc	63.05	8.00	71.05
Glass jars	1,062.97	22.29	1,085.26
Lumber	1,660.21	47.97	1,708.18
Paints, oils, brushes	499.70	....	499.70
Office furniture	765.00	6.00	771.00
Metals	367.14	2.94	370.08
Rubber and leather	122.28	13.32	135.60
Apparatus	129.00	36.32	165.32
Travel	2.00	3.70	5.70
Plumbing	632.00	....	632.00
Total	21,699.63	3,272.59	24,972.22
Balance	3,300.37	27.78	27.78

Heating and lighting, 1891.

Balance July 1, 1892, as per last annual report $1.65

Carried, under the Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1893.

Heating, lighting, etc., 1892.

Balance as per last report, July 1, 1892		$486.44
Expenditure to June 30, 1893:		
Special services	$3.00	
Gas	89.00	
Telephone	201.55	
Electric work	15.00	
Electric supplies	14.44	
Rental of call boxes	20.00	
Heating supplies	81.57	
New boilers	60.00	
Total expenditure		484.56
Balance to meet outstanding liabilities July 1, 1893		1.88

Total expenditures of the appropriations for heating and lighting, etc., 1892.

[Appropriation, $15,000.]

	From July 1, 1891, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total.
Salaries	$5,238.93	$3.00	$5,241.93
Coal and wood	3,365.85	....	3,365.85
Gas	1,360.51	89.00	1,449.51
Telephones	622.65	201.55	824.20
Electric work	37.00	15.00	52.00
Electric supplies	87.53	14.44	101.97
Rental of call boxes	100.00	20.00	120.00
Heating repairs	329.00	....	329.00
Heating supplies	433.62	81.57	515.19
New boilers	2,938.47	60.00	2,998.47
Total	14,513.56	484.56	14,998.12
Balance	486.44	1.88	1.88

SMITHSONIAN INSTITUTION BUILDING.

Repairs.

RECEIPTS.

Balance July 1, 1892, as per last annual report $11,861.08

EXPENDITURES FROM JULY 1, 1892, TO JUNE 30, 1893.

Building material, lime, cement, etc	$317.36	
Carting	138.50	
Glass	22.80	
Hardware	16.03	
Miscellaneous	25.00	
Moving workshop (contract)	115.00	
Paints, oils, etc	77.50	
Pipes and cutters	408.66	
Roofing	263.45	
Slate work	356.00	
Services	2,034.16	
Total expenditure, July 1, 1892, to June 30, 1893		3,774.46
Balance July 1, 1893		8,086.62

ASTROPHYSICAL OBSERVATORY—SMITHSONIAN INSTITUTION, 1893.

Receipts.

Appropriation by Congress "for the maintenance of the Astrophysical Observatory under the direction of the Smithsonian Institution, including salaries of assistants, apparatus, and miscellaneous expenses" (sundry civil act, August 5, 1892.) $10,000.00

Expenditures from July 1, 1892, to June 30, 1893.

Salaries or compensation:

1 senior assistant, $2\frac{1}{2}$ months, at $200 .... $500.00

1 senior assistant, 8 months, at $200, $1,600; 22 days, at $200 per month, $141.94 .... 1,741.94

Salaries or compensation—Continued.			
1 assistant, 15 days, at \$166.66 per month, \$80.64; 15 days, at \$166.66 per month, \$80.64; 10 days, at \$166.66 per month, \$53.76; 2 months, at \$166.66, \$333.32	\$518.36		
1 assistant, 10 days, at \$116 66 per month, \$37.63; 1 month, at \$116.66	154.29		
1 aid, 15 days, at \$40 per month, \$19.35; 15 days, at \$40 per month, \$19.35	38.70		
1 photographer, 6 months, at \$40, \$240; 19 days, at \$40 per month, \$24.52	264.52		
1 photographer, 1½ months, at \$150, \$225; 11 days, at \$150 per month, \$55	280.00		
1 clerk, 3 months, at \$50, \$150; 11 days, at \$50 per month, \$17.74	167.74		
1 copyist, 19 days, at \$35 per month, \$21.45; 1 month, at \$35	56.45		
1 instrument-maker, 14 days, at \$83.33 per month, \$38.34; 7 days, at \$83.33 per month, \$19.44; 4 days, at \$83.33 per month, \$10.75; 5½ days, at \$83.33 per month, \$15.27; ½ month, at \$83.33 per month, \$41.67	125.47		
1 instrument-maker, 15 days, at \$60 per month, \$29.03; 16 days, at \$60 per month, \$30.97; 11 days, at \$60 per month, \$21.29	81.29		
1 instrument-maker, 8 months, at \$60	480.00		
1 janitor, 22 days, at \$40 per month, \$28.39; ½ month, at \$40, \$20	48.39		
1 stenographer, 10 hours, at 50 cents	5.00		
1 carpenter, 5 days, at \$91 per month, \$14.68; 7½ days, at \$91 per month, \$22.02; 8 days, at \$91 per month, \$23.48; 2 days, at \$91 per month, \$6.07; ½ month, at \$91, \$45.50	111.75		
1 carpenter, 2½ days, at \$3, \$7.50; 90$\frac{3}{10}$ hours, \$33.86	41.36		
1 carpenter, 16½ days, at \$3	49.50		
1 carpenter, 19¼ days, at \$3	57.75		
1 laborer, 4½ months, at \$50	225.00		
Total salaries or compensation		\$4,977.51	
General expenses:			
Apparatus and appliances	2,923.46		
Drawings	521.75		
Freight	71.05		
Lumber	49.06		
Miscellaneous supplies	698.12		
Office furniture	48.00		
Postage and telegraph	6.71		
Plumbing and gas-fitting	5.90		
Reference books and binding	234.64		
Stationery	57.76		
Traveling expenses	136.08		
		4,755.53	
Total expenditure, July 1, 1892, to June 30, 1893			\$9,733.04
Balance July 1, 1893, to meet outstanding liabilities			266.96

ASTRO-PHYSICAL OBSERVATORY—SMITHSONIAN INSTITUTION, 1892.

Balance July 1, 1892, as per last annual report		$1,156.39
Expenditures July 1, 1892, to June 30, 1893.		
Apparatus	$634.76	
Drawings	38.25	
Freight	11.53	
Printing and stationery	4.00	
Reference books	366.71	
Salaries	30.00	
Supplies	22.60	
Tools and implements	41.51	
Total expenditure July 1, 1892, to June 30, 1893		1,119.36
Balance July 1, 1893, to meet outstanding liabilities		37.03

NATIONAL ZOOLOGICAL PARK, 1893.

Appropriation by Congress for "continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing the buildings and inclosures for animals; and for administrative purposes, care, subsistence, and transportation of animals, including salaries or compensation of all necessary employés and general incidental expenses not otherwise provided for, $50,000, one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and a report in detail of the expenses on account of the National Zoological Park shall be made to Congress at the beginning of each regular session" (sundry civil act, August 5, 1892)		$50,000.00
Expenditures July 1, 1892, to June 30, 1893.		
Building material, lime, stone, and cement	$2,950.70	
Fuel	829.04	
Copper, cornice (contract)	288.00	
Food for animals	3,832.08	
Freight, transportation, and hauling	990.19	
Iron, steel, piping, fencing, and hardware	2,615.17	
Lumber	1,560.81	
Paints, oils, etc	80.91	
Postage, telephone, and telegraph	148.08	
Stationery, printing, etc	301.00	
Surveying, plans, drawings, etc	1,014.00	
Traveling expenses	60.89	
Tools and implements	350.61	
Trees, plants, fertilizers, etc	258.86	
Water supply, sewerage, etc	619.43	
Supplies	560.37	
Salaries or compensation	18,181.51	
Labor, constructing wing walls of bridge, riprapping banks of creek, buildings, inclosures, and ponds, roads, and banks, and laying water pipes	13,126.34	
Total expenditures		$47,801.02
Balance July 1, 1893, to meet outstanding liabilities		2,198.98

Organization, improvement, maintenance.

Balance July 1, 1892, as per last annual report		$1,778.34

Expenditures from July 1, 1892, to June 30, 1893.

Artificial ponds, etc	$910.86	
Current expenses	23.75	
		$934.61
Balance July 1, 1893, to meet outstanding liabilities		843.73

Statement of the total expenditures of the appropriation for the Zoological Park, act of April 30, 1890.

	From April 30, 1890, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total to June 30, 1893.
Shelter of animals	$14,925.21		$14,925.21
Shelter barns, cages, fences, etc	8,956.06		8,956.06
Repairs to Holt mansion, etc	2,000.00		2,000.00
Artificial ponds, etc	1,089.14	$910.86	2,000.00
Water supply, sewerage, and drainage	7,000.00		7,000.00
Roads, walks, and bridges	15,000.00		15,000.00
Miscellaneous supplies	5,000.00		5,000.00
Current expenses	36,251.25	23.75	36,275.00
Total	90,221.66	934.61	91,156.27
Balance	1,778.34	843.73	843.73

National Zoological Park—buildings, 1892.

Balance July 1, 1892, as per last report	$231.54
Expenditures, July 1, 1892, to June 30, 1893:	
Lumber	140.74
Paints, oils, etc	38.43
Plans, drawings, etc	13.25
Plumbing supplies	14.12
Stone	25.00
	231.54

Statement of the total expenditures of the appropriation for National Zoological Park—buildings, 1892.

[Appropriation, $18,000; act March 3, 1891.]

	From July 1, 1891, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total to June 30, 1893.
Fencing	$107.50		$107.50
Fuel	4.20		4.20
Glass, paints, oils, etc	227.40	$38.43	265.83
Hardware, tools, etc	1,249.98		1,249.98
Heating apparatus	3,545.00		3,545.00
Lumber	3,023.41	140.74	3,164.15
Miscellaneous	83.10		83.10
Plans, drawings, etc	575.00	13.25	588.25
Plumbing supplies		14.12	14.12
Salaries or compensation	8,624.32		8,624.32
Stone, brick, lime, cement	328.55	25.00	353.55
Total	17,768.46	231.54	18,000.00

National Zoological Park—improvements, 1892.

Balance July 1, 1892, as per last annual report		$121.34
Expenditures July 1, 1892, to June 30, 1893:		
Hardware	$7.54	
Plans and drawings	100.00	
Trees, shrubs, plants, etc	8.80	
		116.34
Balance July 1, 1893, to meet outstanding liabilities		5.00

Statement of the total expenditure of the appropriation for the National Zoological Park:—Improvements, 1892.

[Appropriation, $15,000, act March 3, 1891.]

	From July 1, 1891, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total to June 30, 1893.
Building bridge (contract)	$1,742.50		$1,742.50
Building material	544.17		544.17
Freight	74.00		74.00
Hardware	17.20	$7.54	24.74
Lumber	333.09		333.09
Salaries or compensation	8,181.84		8,181.84
Settees, etc	420.00		420.00
Supplies	81.95		81.95
Surveying, plans, and drawings	2,961.79	100.00	3,061.79
Tools and implements	173.77		173.77
Traveling expenses, etc	68.50		68.50
Trees, plants, and fertilizers	279.85	8.80	288.65
Total	14,878.66	116.34	14,995.00
Balance July 1, 1893, to meet outstanding liabilities			$5.00

National Zoological Park:—Maintenance, 1892.

Balance July 1, 1892, as per last annual report	$1,386.50
Expenditures from July 1, 1892, to June 30, 1893:	
Coal and wood	180.00
Draft-horses	365.00
Food and animals	189.28
Freight and hauling	2.65
Miscellaneous expenses	99.03
Plans, drawings, etc	200.00
Specimens	296.17
Stationery and printing	16.87
Telephones	37.50
	1,386.50

Statement of the total expenditure of the appropriation for the National Zoological Park—maintenance, 1892.

[Appropriation, $18,500, acts March 3, 1891, and March 8, 1892.]

	From July 1, 1891, to June 30, 1892.	From July 1, 1892, to June 30, 1893.	Total to June 30, 1893.
Coal and wood	$263.12	$180.00	$443.12
Draft-horses		365.00	365.00
Food for animals	3,738.12	189.28	3,927.40
Freight and hauling	222.91	2.65	225.56
Hardware, etc	76.05		76.05
Horseshoeing	33.14		33.14
Lumber	27.50		27.50
Miscellaneous expenses	394.22	99.03	493.25
Plans, drawings, etc		200.00	200.00
Salaries or compensation	10,984.12		10,984.12
Stationery and printing	72.77	16.87	89.64
Specimens	1,301.55	296.17	1,597.72
Telephones		37.50	37.50
Total	17,113.50	1,386.50	18,500.00

RECAPITULATION.

The total amount of funds administered by the institution during the year ending June 30, 1893, appears from the foregoing statements and the account books to have been as follows:

Smithsonian Institution.

From balance of last year, July 1, 1892		$47,875.33	
(Including cash from executors of Dr. J. H. Kidder	$5,000.00		
Including cash from gift of Dr. Alex. Graham Bell)	5,000.00		
	10,000.00		
From interest on Smithsonian fund for the year		54,180.00	
From sales of publications		556.58	
From repayments of freight, etc		3,235.96	
			$105,847.87

Appropriations committed by Congress to the care of the Institution.

International exchanges—Smithsonian Institution:		
From appropriation for 1892–'93		$17,000.00
North American ethnology:		
From balance of last year, July 1, 1892	$15,008.06	
From appropriation for 1892–'93	40,000.00	
		55,008.06
Preservation of collections—Museum:		
From balance of 1890–'91	291.58	
From balance of 1891–'92, July 1, 1892	8,818.14	
From appropriation 1892–'93	134,500.00	
		143,609.72
Printing—Museum:		
From balance of 1891–'92	4,839.43	
From appropriations for 1892–'93	12,000.00	
		16,839.43

Furniture and fixtures—Museum:		
From balance of 1891	$2.35	
From balance of 1891–'92	3,300.37	
From appropriation 1892–'93	15,000.00	
		$18,302.72
Heating and lighting, etc.—Museum:		
From balance of 1891	1.65	
From balance of 1891–'92, July 1, 1892	486.44	
From appropriation for 1892–'93	13,000.00	
		13,488.09
Postage—Museum:		
From appropriation for 1892–'93		500.00
Building—National Museum:		
From balance for 1891–'92		525.36
Duties on articles imported for the National Museum:		
From balance for 1891–'92		58.25
National Zoological Park:		
From balance of 1889–'90, July 1, 1891	$1,778.34	
From balance of 1891–'92	1,739.38	
From appropriation, 1892–'93	50,000.00	
		53,517.72
Smithsonian Institution building—repairs:		
From balance of appropriation, July 1, 1892		11,861.08
Astro-Physical Observatory, Smithsonian Institution:		
From balance of July 1, 1892	$1,156.39	
From appropriation for 1892–'93	10,000.00	
		11,156.39

SUMMARY.

Smithsonian Institution	$105,847.87
Exchanges	17,000.00
Ethnology	55,008.06
Preservation of collections	143,609.72
Furniture and fixtures	18,302.72
Heating and lighting	13,488.09
Postage	500.00
Printing	16,839.43
Building, National Museum	525.36
Duties on articles for National Museum	58.25
National Zoological Park	53,517.72
Smithsonian Institution building, repairs	11,861.08
Astro-Physical Observatory	11,156.39
	$447,714.69

The committee has examined the vouchers for payment from the Smithsonian income during the year ending June 30, 1893, each of which bears the approval of the secretary, or in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution.

The committee has also examined the accounts of the several appropriations committed by Congress to the Institution and finds that the balances hereinbefore given correspond with the certificates of the disbursing clerk of the Smithsonian Institution, whose appointment as

such disbursing officer has been accepted and his bonds approved by the Secretary of the Treasury.

The quarterly accounts-current, the vouchers, and journals have been examined and found correct.

Statement of regular income from the Smithsonian fund available for use in the year ending June 30, 1894.

Balance on hand June 30, 1893		$57, 092. 82
(Including the cash from executors of J. H. Kidder)	$5, 000. 00	
(Including the cash from Dr. Alex. Graham Bell)	5, 000. 00	
	10, 000. 00	
Interest due and receivable July 1, 1893	27, 090. 00	
Interest due and receivable January 1, 1894	27, 090. 00	
		54, 180. 00
Total available for year ending June 30, 1894		111, 272. 82

Respectfully submitted,

JAMES C. WELLING,
HENRY COPPÉE,
J. B. HENDERSON,
Executive Committee.

WASHINGTON, D. C., *November 18, 1893.*

ACTS AND RESOLUTIONS OF CONGRESS RELATIVE TO THE SMITHSONIAN INSTITUTION, NATIONAL MUSEUM, ETC.

(In continuation from previous Reports.)

[Fifty-second Congress, second session, 1893.]

SMITHSONIAN INSTITUTION.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the vacancy in the Board of Regents of the Smithsonian Institution, of the class other than Members of Congress, shall be filled by the reappointment of James B. Angell, of Michigan, whose term of office expires on January 19, 1893. (Joint Resolution No. 4. Approved, January 9, 1893.)

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Smithsonian Institution be, and he hereby is, authorized to prepare and send, for exhibition in the Woman's Building of the World's Columbian Exposition, any article now in his custody, or on exhibition in the National Museum, illustrative of the life and development of the industries of women. (Joint Resolution No. 19. Approved, March 3, 1893. Statutes, Vol. XXVII, p. 757.)

Smithsonian building.—For completing the repairs upon the Smithsonian building, and for such other work as is needed to protect the building from further deterioration, and to place it in proper sanitary condition, any unexpended balance remaining to the credit of the appropriation for fireproofing, and so forth, shall be available for the purposes above stated; this work to be done under the direction of the Architect of the Capitol, and in accordance with the approval of the Secretary of the Smithsonian Institution. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 581.)

War Department.—Buildings and grounds.—For improvement, maintenance, and care of Smithsonian grounds, including construction of asphalt roads and paths, two thousand five hundred dollars. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 597.)

For two day watchmen in Smithsonian grounds, at six hundred and sixty dollars each, one thousand three hundred and twenty dollars.

For two night watchmen in Smithsonian grounds, at seven hundred and twenty dollars each, one thousand four hundred and forty dollars. (Legislative, executive, and judicial act. Approved, March 3, 1893. Chap. 211, Statutes, p. 700.)

INTERNATIONAL EXCHANGES.

For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, fourteen thousand five hundred dollars. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 582.)

For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, five thousand dollars. (Deficiency appropriation act. Approved, March 3, 1893. Chap. 210, Statutes, p. 649.

War Department.—For the transportation of reports and maps to foreign countries through the Smithsonian Institution, one hundred dollars. (Sundry civil act. Approved, March 3, 1893. Chap. 208, Statutes, p. 600.)

Navy Department.—Naval Observatory.—For repairs to buildings, fixtures, and fences, gas, furniture, chemicals, stationery, freight, including transmission of public documents through the Smithsonian exchange, foreign postage, expressage, plants, fertilizers, and all contingent expenses, two thousand five hundred dollars. (Legislative, executive, and judicial act. Approved, March 3, 1893. Chap. 211, Statutes, p. 702.)

Department of the Interior.—United States Patent Office.—For purchase of professional and scientific books and expenses of transporting publications of patents issued by the Patent Office to foreign governments, two thousand dollars. (Legislative, executive, and judicial act. Approved, March 3, 1893. Chap. 211, Statutes, p. 706.)

United States Geological Survey—For the purchase of necessary books for the library, and the payment of the transmission of public documents through the Smithsonian exchange, two thousand dollars. (Sundry civil act. Approved, March 3, 1893. Chap. 208, Statutes, p. 595.)

NATIONAL MUSEUM.

For continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees, one hundred and thirty-two thousand five hundred dollars.

For cases, furniture, fixtures, and appliances required for the exhibition and safe keeping of the collections of the National Museum, including salaries or compensation of all necessary employees, ten thousand dollars.

For expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum, eleven thousand dollars.

For postage stamps and foreign postal cards for the National Museum, five hundred dollars. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 581.)

For expenses of heating the United States National Museum, two thousand dollars.

For continuing the preservation, exhibition, and increase of the collection from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees, two thousand dollars. (Deficiency appropriation act. Approved, March 3, 1893. Chap. 210, Statutes, p. 649.)

Treasury Department.—Under Smithsonian Institution: For preservation of collections, National Museum, one dollar and thirty seven cents. (Deficiency appropriation act. Approved, March 3, 1893. Chap. 210, Statutes, p. 668.)

Public printing and binding.—For the Smithsonian Institution, for printing labels and blanks and for the "Bulletins" and annual volumes of the "Proceedings" of the National Museum, twelve thousand dollars. (Sundry civil appropriation act. Approved, March 31, 893. Chap. 208, Statutes, p. 611.)

SEC. 3. That hereafter no building owned or used for public purposes by the Government of the United States shall be draped in mourning and no part of the public fund shall be used for such purpose.

SEC. 4. That hereafter the Executive Departments of the Government shall not be closed as a mark to the memory of any deceased ex-official of the United States. (Legislative, executive, and judicial act. Approved, March 3, 1893.)

NORTH AMERICAN ETHNOLOGY.

For continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, forty thousand dollars, of which sum not exceeding one thousand dollars may be used for rent of building. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 582.)

ASTRO-PHYSICAL OBSERVATORY.

For maintenance of astro-physical observatory, under the direction of the Smithsonian Institution, including salaries of assistants, apparatus, and miscellaneous expenses, nine thousand dollars. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 582.)

NATIONAL ZOOLOGICAL PARK.

For continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures for animals; and for administrative purposes, care, subsistence, and transportation of animals, including salaries or compensation of all necessary employees, and general incidental expenses not otherwise provided for, fifty thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; a report in detail of the expenses on account of the National Zoological Park shall be made to Congress at the beginning of each regular session. (Sundry civil appropriation act. Approved, March 3, 1893. Chap. 208, Statutes, p. 582.)

WORLD'S COLUMBIAN EXPOSITION AT CHICAGO.

Treasury Department.—For the selection, purchase, preparation, transportation, installation, care and custody, and return of such articles and materials as the heads of the several Executive Departments, the Smithsonian Institution and National Museum, and the United States Fish Commission may decide shall be embraced in the Government exhibit, and such additional articles as the President may designate

for said Exposition, and for the employment of proper persons as officers and assistants to the Board of Control and Management of the Government exhibit, appointed by the President, of which not exceeding ten thousand dollars may be expended by said board for clerical services, one hundred and fifty thousand seven hundred and fifty dollars: of which sum fifty thousand dollars shall be immediately available: *Provided*, That the sum of eight thousand dollars, or so much thereof as may be necessary, may be expended under the supervision of the Board of Control of the United States Government exhibit in the collection, preparation, packing, transportation, installation, and care while exhibited of articles loaned or donated by the colleges of agriculture and mechanic arts in the several States for the display in the agricultural building of the Exposition, of the means and methods of giving instruction in the so-called land-grant college of the United States, and for repacking and returning this property at the close of the Exposition, the same to be taken from the sum apportioned to the Agricultural Department: and ten thousand dollars additional for special expenses attending the naval exhibit of the model of a battle ship. (Sundry civil appropriation act. Approved, March 3, 1893, Chap. 208, Statutes, p. 585.)

REPORT OF S. P. LANGLEY,

SECRETARY OF THE SMITHSONIAN INSTITUTION,

FOR THE YEAR ENDING JUNE 30, 1893.

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit herewith a report of the operations of the Smithsonian Institution for the year ending June 30, 1893, including the work placed by Congress under its supervision in the National Museum, the Bureau of Ethnology, the Bureau of International Exchanges, the Zoölogical Park, and the Astro-Physical Observatory.

I have endeavored to give in the body of the report, and as briefly as possible, a general account of the affairs of the Institution for the year, reserving for the appendix the more detailed and statistical reports from the officers in charge of the different branches of work.

The report upon the National Museum by the Assistant Secretary, Dr. G. Brown Goode, is here given only in abstract. Its full presentation occupies a separate volume. (Report of the Smithsonian Institution, National Museum, 1893.)

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

Since the change of executive officers of the United States Government on March 4, 1893, the Smithsonian establishment consists of the following *ex officio* members:

GROVER CLEVELAND, *President of the United States.*
ADLAI E. STEVENSON, *Vice-President of the United States.*
MELVILLE W. FULLER, *Chief Justice of the Supreme Court of the United States.*
WALTER Q. GRESHAM, *Secretary of State.*
JOHN G. CARLISLE, *Secretary of the Treasury.*
DANIEL S. LAMONT, *Secretary of War.*
HILARY A. HERBERT, *Secretary of the Navy.*
WILSON S. BISSELL, *Postmaster-General.*
RICHARD OLNEY, *Attorney-General.*
JOHN S. SEYMOUR, *Commissioner of Patents.*

The Hon. W. E. Simonds was succeeded on April 16, 1893, as Commissioner of Patents by the Hon. John S. Seymour.

THE BOARD OF REGENTS.

In accordance with a resolution of the Board of Regents adopted January 8, 1890, by which its stated annual meeting occurs on the fourth Wednesday in each year, the board met on January 25, 1893, at 10 o'clock A. M. The journal of its proceedings will be found, as hitherto, in the annual report of the board to Congress, though reference is here made to several matters upon which action was taken at this meeting.

The changes that have taken place in the membership of the Board of Regents have been—

First, through the death of Senator R. L. Gibson, which occurred on December 15, 1892. Senator George Gray, of Delaware, was appointed on December 20, 1892, by the Vice-President to fill the unexpired term of Senator Gibson, and having been re-elected as Senator from Delaware, was re-appointed Regent on March 16, 1893.

A brief sketch of Senator Gibson's life is given in the necrological notices that close the present report, but I may quote here the following resolutions prepared by a committee consisting of Dr. Wm. Preston Johnston, Senator J. S. Morrill, and the Secretary, which were presented at the meeting of the Regents on January 25, 1893:

Resolved, That in the death of Hon. Randall Lee Gibson, the Smithsonian Institution has lost a zealous and useful Regent, and its board a valuable member whose services can ill be spared.

Resolved, That we lament his loss as an acceptable colleague, a gracious gentleman, a patriotic citizen, and a wise statesman, whose interest in the spread of knowledge among men fitted him well for his duties on the board.

Resolved, That these resolutions be entered on the minutes of the board, and a copy be transmitted to the family of our friend.

Second, President James B. Angell, of the University of Michigan, whose previous term of office expired on January 13, 1893, was reappointed for six years by a joint resolution introduced by Senator J. S. Morrill, of Vermont, which passed the Senate on December 20, 1892, the House of Representatives on January 6, 1893, and was approved by the President January 10, 1893.

ADMINISTRATION.

I have called attention to the desirability of securing from Congress an appropriation to meet actual outlays incurred in administering Governmental trusts. These direct outlays for matters not equitably chargeable to the fund of James Smithson, are growing a more considerable tax upon it each year. They are incurred in serving purely Governmental interests, but they are not met by any of the present appropriations, since they belong not singly to the National Museum, or the Bureau of Ethnology, or to the International Exchange service, or the like, but to expenditures common to all of them, and which are not provided for by the terms of the appropriations for any one.

It is in the interests of economy that this expenditure should be met from some common source, owing to the limited size of the establishments in question, some of which are rather assimilable to divisions than to bureaus. It is evident, for instance, that an appropriation of $17,000 for international exchanges, or an appropriation of $10,000 for an observatory, can not each so well bear the separate provision of a disbursing officer, a stenographer, and the other like employés, as in the case of larger bureaus, but that their limited needs can be better and more economically managed by not duplicating such offices. There is, however, no practicable way of arranging this in compliance with the present terms of the appropriations, which may be said to tacitly assume that each of these bureaus or divisions is thus completely provided for.

It is in some cases impossible that it should be so without the expenditure of greatly more than the appropriated sum, and the terms of the appropriations should in the interest of economy, either recognize the propriety of meeting each bureau's share of these common expenses out of each one's appropriation, or else out of a special appropriation made in their common interest.

FINANCES.

The permanent funds of the Institution remain the same as at the time of my last report, and are as follows:

Bequest of Smithson, 1846	$515,169.00
Residuary legacy of Smithson, 1867	26,210.63
Deposits from savings of income, 1867	108,620.37
Bequest of James Hamilton, 1875	1,000.00
Bequest of Simeon Habel, 1880	500.00
Deposits from proceeds of sale of bonds, 1881	51,500.00
Gift of Thomas G. Hodgkins, 1891	200,000.00
Total permanent fund	903,000.00

This sum of $903,000 is deposited in the Treasury of the United States, and by act of Congress bears interest at 6 per cent per annum, the interest alone being used in carrying out the aims of the Institution.

At the beginning of the fiscal year, July 1, 1892, the balance on hand was $47,875.33. Interest on the invested funds, amounting to $54,180, was received during the year, which, together with a sum of $3,792.54, received from the sale of publications, and from miscellaneous sources, made the total receipts $57,972.54.

The total expenditure during the year was $48,755.05, for the details of which reference is made to the report of the executive committee. The unexpended balance on June 30, 1893, was $57,092.82, which includes the sum of $10,000 referred to in previous reports, $5,000 having been received from the estate of Dr. Kidder, and a like sum from Dr. Alexander Graham Bell, the latter a gift made personally to the Secretary to promote certain physical investigations.

This latter sum was, with the donor's consent, deposited by the Secretary to the credit of the current funds of the Institution.

This $10,000 is not, then, a portion of the invested funds, but is held partly to erect a building whenever Congress shall provide a site for a permanent Astrophysical Observatory, and partly to meet anticipated expenditures in certain investigations.

This balance also includes the interest accumulated on the Hodgkins donation and on the Hamilton fund, which is awaiting the Regents' disposition, besides certain relatively considerable sums held to meet obligations which may be expected to mature as the result of different scientific investigations or publications in progress.

The Institution has been charged with the disbursement, during the fiscal year 1892–'93, of the following appropriations:

For international exchanges	$17,000
For North American Ethnology	40,000
For U. S. National Museum:	
Preservation of collections	134,500
Furniture and fixtures	15,000
Heating and lighting	13,000
Postage	500
For National Zoological Park	50,000
For Astrophysical Observatory	10,000

All vouchers and checks for the disbursements have been examined by the executive committee, and the expenditures will be found reported in accordance with the provisions of the sundry civil act of October 2, 1888, in a letter addressed to the Speaker of the House of Representatives.

The vouchers for all the expenditures from the Smithsonian fund proper have been likewise examined and their correctness certified to by the executive committee, whose statement will be published together with the accounts of the funds appropriated by Congress, in that committee's report.

The estimates for the fiscal year ending June 30, 1894, for carrying on the Government interests under the charge of the Smithsonian Institution, were as follows:

International exchange	$23,000
North American Ethnology	50,000
National Museum:	
Preservation of collections	180,000
Heating and lighting	15,000
Furniture and fixtures	30,000
Postage	500
Galleries	8,000
National Zoological Park	75,000
Astrophysical Observatory	10,000
Building, Smithsonian Institution	5,000

With regard to the general expenditures of the Institution, it may be remarked that those for clerical services and for incidental expen-

ses have for the last seven years, owing to increasing economies, been diminishing until they are now considerably less in proportion to the amount administered than at any former time. It is doubtful whether these economies can be advantageously pushed any further, as it has become difficult, with the present force, to keep abreast of the actual current demands, and there has been no considerable renewal of the perishable furnitures of the building during the period mentioned. It seems probable, therefore, that the proportionate cost of these items is not likely to be again lower than it is at present.

BUILDINGS.

It may perhaps seem superfluous, in consideration of the serious reductions that have been made in the appropriations for the current expenses of the Museum, to repeat my recommendation that more adequate accommodations should be provided for it by the erection of a new and thoroughly fireproof building, but while this is needed for many reasons, the repetition is opportune now, since valuable material may come to the Museum at the close of the World's Columbian Exposition in Chicago, and because if there are storage and exhibition rooms available, many exhibits at Chicago may be secured, which it will otherwise perhaps be necessary to refuse.

I must repeat what I have stated in previous reports, that since the present Museum building was finished and occupied in 1881, the collections have increased to such an extent that a new building quite as large as the present one could have been advantageously filled, and that the need grows yet more pressing.

The improvement of buildings in the Zoological Park to the limited extent that the appropriations allowed, is detailed in the report of the acting manager.

REPAIRS TO THE SMITHSONIAN BUILDING.

A restrictive clause contained in the appropriation of August 30, 1890, for repairs to the Smithsonian building was removed by a clause in the sundry civil act for the year ending June 30, 1894, so that a portion of the amount unexpended became available for making necessary repairs to the roof of the eastern wing and improving the sanitary condition of the building, as well as for increasing the space available for storing documents and handling the Government exchanges. The plumbing in the eastern part of the building has been thoroughly overhauled, and a suite of dark and damp rooms in the basement on the south side has been transformed into well-lighted and comfortable offices, thus freeing several rooms upon the first floor, needed for other purposes, and making it possible to handle more expeditiously the great number of books passing through the exchange office; though even with these new rooms, additional storeroom for the Government exchanges will be called for at no distant day.

It may be of interest to note that a mark was placed, by my direction, at the side of the window of the northeast corner room in the basement of the Smithsonian building, 31 feet above the datum plane used by the engineer office of the District of Columbia, situated at the corner of Fifteenth and B streets NW., or about 19.87 feet above the highest flood mark recorded, that of June 2, 1889.

RESEARCH.

It appears to be an essential portion of the original scheme of the government of the Institution that its Secretary should be expected to advance knowledge, whether in letters, or in science, by personal research; and resolutions of the Regents formally request the Secretary to continue his investigations in physical science, and to present their results for publication in the Smithsonian "Contributions."

The advancement of science through original research at the hands of those eminent men, Henry and Baird, the former Secretaries of this Institution, is known to all, but though the Secretary may be still expected to personally contribute to the advancement of science, or art, or letters, by his individual efforts, it is certain that the increasing demands of time for labors of administration had greatly limited the possibility of this, even in the time of Henry, and that at the present day administrative duties, and especially those connected with the care of Government interests, constitute a barrier to such investigations, which is all but impassable.

I have never abandoned, however, the hope to thus continue the tradition of the Institution and the usage of former Secretaries by personally contributing, as far as I could, to the objects stated, and I have, where administrative duties would permit, continued during the present year the researches, of which a portion has been published, in August, 1891, in a treatise entitled "Experiments in Aerodynamics." Interesting results have since been reached here, which appear to be of wide utilitarian importance, but though I trust, before the close of another year, to be able to make some communication of them to the public, they are not yet complete.

In this same connection, in pursuit of an investigation begun some years ago, and in continuation of the Institution's interest in the promotion of meteorological studies, I have made experiments upon the variations continually going on in the atmosphere, in what is regarded for ordinary meteorological purposes as a steady wind. Specially light anemometers have been constructed and mounted upon the north tower of the Smithsonian building, and connected with a suitable recording apparatus. The results, which promise conclusions of practical importance, are being collated and will be published at a later date. I am under obligations to the Chief of the U. S. Weather Bureau for the loan of a portion of these anemometers, the others having been constructed in the small workshop of the Institution.

I have continued to give what time and thought I can to investigations in astro-physics, which are so extensive and, I hope, so important, as to justify a considerable separate mention under the title, Astro-physical Observatory, in the Appendix of this report.

In what I have said I have principally referred to research in the physical sciences, since aid to original research in the biological sciences has been largely, though indirectly, provided through the Institution's connection with the National Museum and otherwise. It would, therefore, seem proper that what aid to scientific men can be given from the original Smithsonian fund should be principally devoted to the physical sciences, which are not otherwise cared for.

As in previous years, aid to a limited extent has been given to original investigators who are not immediately connected with the Institution. Prof. E. W. Morley has continued his determinations of the density of oxygen and hydrogen, for which special apparatus has been provided by the Institution.

A paper by Prof. A. A. Michelson, upon the "Application of interference methods to spectroscopic measurements," with a view to increased precision in measuring specific wave-lengths of light, has been published in connection with his work upon a universal standard of length. Mr. F. L. O. Wadsworth was detached from the Observatory staff, and sent (at the expense of the Smithsonian fund) to the Bureau Internationale des Poids et Mésures near Paris to assist Prof. Michelson during a stay of six weeks in the preparation of this standard.

Prof. Holden, the director of the Lick Observatory, Mount Hamilton, Cal., is still engaged in lunar photography, for which some occasional aid has been given in previous years by the Institution.

The subscription for twenty copies of the Astronomical Journal, which are distributed abroad as exchanges of the Institution, has been continued.

In the Astro-physical Observatory the investigations of radiant energy alluded to in my previous reports have been continued, and very interesting results have been obtained. I have referred, on another page, somewhat at length to the work of the Observatory, and further details are contained in the report in the Appendix.

The Hodgkins researches have already promised to assume such importance that they have also been given a special place upon a later page of the present report.

EXPLORATIONS.

I am much gratified to report the safe return of Mr. W. W. Rockhill from his dangerous journey in Tibet. His explorations have added much to our knowledge of these regions, and a portion of the collection he has made will eventually be placed in the National Museum. Mr. Rockhill is now engaged upon the preparation of a special report of

his journey, which will be published in the Miscellaneous Collections of the Institution, while a brief popular abstract of his paper is now in print and will form a part of the Appendix to the Annual Report of the Regents for the year ending June 30, 1892, soon to be issued.

The principal other explorations of the Institution have been made through the Bureau of Ethnology, to the report of whose Director the reader is referred.

PUBLICATIONS.

Smithsonian Contributions to Knowledge.—The quarto series of publications under this title, inaugurated by the Institution in 1848, has always been regarded as the most important of its issues—not merely by priority in date, but as including only memoirs of extended original investigations and researches, advancing what are believed to be new truths, and constituting therefore positive additions to human knowledge.

The hope of its originator—the first Secretary—to be able to send forth a quarto volume annually (after the practice of the Royal Society of London), has not been realized; partly from the insufficiency of material presented judged worthy of the position, partly from the cost.

Volume XXVIII of the "Contributions to Knowledge" has been issued during the year, consisting entirely of a memoir entitled "Life Histories of North American Birds, with special reference to their breeding habits and eggs," by Capt. Charles E. Bendire (U. S. Army, retired), honorary curator of the oölogical collections in the U. S. National Museum. This somewhat elaborate work is illustrated with well-executed chromo-lithographic plates of birds' eggs, representing eight families and over 100 different species. It has been received with exceptional favor by European as well as by American men of science.

Another memoir published during the year, which, though brief, is regarded as an important scientific "contribution," is a discussion, by Prof. A. A. Michelson, of "the application of interference methods to spectroscopic measurements," with a view to an increased precision in measuring specific wave-lengths of light, which may ultimately be employed as fixed standards of comparison for units of linear metrology.

Smithsonian Miscellaneous Collections.—Of this series two volumes have been issued during the year, Volumes XXXIV and XXXVI, the former comprising a collection of ten articles previously published separately.

The latter consists of a new bibliography of chemistry for the past four hundred years, a work of remarkable research by Dr. Henry Carrington Bolton, extending to more than 1,200 octavo pages.

Volume XXXV of this series has not yet been completed, though the first contribution thereto has been issued, namely, a volume of "Smithsonian meteorological tables" of over 300 pages. It forms the first of three projected volumes of tables—(A) meteorological, (B) geograph-

ical, (C) physical—designed to supersede the tables of Dr. Guyot, first published by this Institution in 1852, which have had so wide and so useful a currency, but which are now so far out of date that it seems better to replace than to revise and reprint them.

Smithsonian Annual Reports.—The report of the U. S. National Museum to the Secretary of the Smithsonian Institution for the year ending June 30, 1890, has only been received from the printer this year. The Smithsonian Report for the year ending June 30, 1891, as well as the Museum Report for the same period, have not yet been received from the Government Printing Office.

Reports of the Bureau of Ethnology.—The Seventh Annual Report of the Director of the Bureau of Ethnology to the Secretary of the Smithsonian Institution, published during the year, maintains the usual character of excellence.

LIBRARY.

The plan detailed in my report for 1887–'88 for increasing the accessions to the library and for completing the series of scientific journals already in possession of the Institution has been continued, with gratifying results. Since the plan was first put in operation 1,350 new periodicals have been added to the list and 909 defective series have been either completed or filled out as far as the publishers were able to supply missing parts.

The reading room no longer has sufficient accommodations for the growing exchanges of the Institution, nor for the persons desiring to consult this important collection of current scientific literature.

Ever since 1890 I have called attention in my reports to the fact that the present quarters of the library are insufficient, the natural expansion of the library having been prevented by the fact that the rooms adjacent to it were occupied by the international exchanges. It will be possible shortly to assign other quarters to the exchanges, and plans have been prepared for book shelves and a gallery in one of the rooms made vacant. It is estimated that space will thus be secured for about 6,000 volumes.

Mr. John Murdoch, whose resignation as librarian was referred to in my last report, was succeeded in charge of the library on July 16, 1892, by Mr. J. Elfreth Watkins.

Mr. Watkins on October 1, 1892, resigned his position, and on December 1, 1892, Dr. Cyrus Adler, of the Johns Hopkins University, was appointed to fill the vacancy. Dr. Adler's report on the library for the year is given in Appendix IV.

The Institution has possessed for many years a number of costly illustrated works of art, engravings and etchings, which were acquired by the Regents, by purchase, of the late Mr. Marsh, our minister at Rome. These were understood to have been temporarily deposited with the Library of Congress for safekeeping in 1874. Some correspondence

with regard to them took place between the Secretary and the Librarian on May 10 of the present year, from which it appears that the bound volumes are, in general, accessible, but that a large portion of the unbound engravings which the catalogue—an imperfect one,—appears to call for,—can not at present be found, nor is it, indeed (owing to the imperfection of the present catalogue and lists), yet certain that all of these were in fact sent to the Library of Congress.

I mention in connection with the expression of the interest that the Institution is intended to take in art, the fact that the Regents, at their meeting of October, 1891, having instructed the Secretary to cause to be painted a portrait of Mr. Hodgkins, he placed the execution of this in the hands of Mr. Robert Gordon Hardie, who produced (though aided only by a photograph and a description given by friends) a portrait of Mr. Hodgkins both valuable as a work of art and singularly true as a likeness. This was submitted to the Regents at their meeting in January, and received their general approbation.

In this same connection it may be observed that the portrait of Henry, executed by the Regents' instructions in former years, was sent to form a portion of the Smithsonian exhibit at the World's Fair in Chicago.

THE HODGKINS FUND.

As stated in the Secretary's Report for 1892, the gift to the Smithsonian Institution of $200,000 by Mr. Thomas George Hodgkins, of Setauket, N. Y., was formally accepted at a special meeting of the Board of Regents on the 21st of October, 1891.

On the 23d of the same month Mr. Hodgkins added to his will a codicil making the Smithsonian Institution his residuary legatee, but the sum thus added to the original gift will not, it is understood, be considerable.

The committee appointed to advise upon matters connected with the Hodgkins foundation* submitted the following circular, which was approved, and published in March, 1892, and has since then been widely distributed, more than 8,000 copies having been sent throughout the world to learned institutions and to investigators, and, on request, to all expressing themselves interested in the researches which, in accordance with the wish of the founder, it is the design to have specially furthered by the income from the Hodgkins fund.

SMITHSONIAN INSTITUTION.

[Presiding officer *ex officio:* The President of the United States. Chancellor: The Chief Justice of the United States. All correspondence should be addressed to the secretary, S. P. Langley.]

CIRCULAR CONCERNING THE HODGKINS FUND PRIZES.

In October, 1891, Thomas George Hodgkins, Esq., of Setauket, N. Y., made a donation to the Smithsonian Institution, the income from a part of which was to be devoted "to the increase and diffusion of more

* See Secretary's Report for 1892, p. 20.

exact knowledge in regard to the nature and properties of atmospheric air in connection with the welfare of man."

With the intent of furthering the donor's wishes, the Smithsonian Institution now announces the following prizes, to be awarded on or after July 1, 1894, should satisfactory papers be offered in competition:

(1) A prize of $10,000 for a treatise embodying some new and important discovery in regard to the nature or properties of atmospheric air. These properties may be considered in their bearing upon any or all of the sciences, e. g., not only in regard to meteorology, but in connection with hygiene, or with any department whatever of biological or physical knowledge.

(2) A prize of $2,000 for the most satisfactory essay upon (*a*) the known properties of atmospheric air, considered in their relationships to research in every department of natural science, and the importance of a study of the atmosphere, considered in view of these relationships; (*b*) the proper direction of future research, in connection with the imperfections of our knowledge of atmospheric air, and of the connections of that knowledge with other sciences.

The essay, as a whole, should tend to indicate the path best calculated to lead to worthy results in connection with the future administration of the Hodgkins foundation.

(3) A prize of $1,000 for the best popular treatise upon atmospheric air, its properties and relationships (including those to hygiene, physical and mental). This essay need not exceed 20,000 words in length; it should be written in simple language, and be suitable for publication for popular instruction.

(4) A medal will be established, under the name of *The Hodgkins Medal of the Smithsonian Institution*, which will be awarded annually or biennially, for important contributions to our knowledge of the nature and properties of atmospheric air, or for practical applications of our existing knowledge of them to the welfare of mankind. This medal will be of gold, and will be accompanied by a duplicate impression in silver or bronze.

The treatises may be written in English, French, German, or Italian, and should be sent to the Secretary of the Smithsonian Institution, Washington, before July 1, 1894, except those in competition for the first prize, the sending of which may be delayed until December 31, 1894.

The papers will be examined and prizes awarded by a committee to be appointed as follows: One member by the Secretary of the Smithsonian Institution; one member by the president of the National Academy of Sciences; one by the president *pro tempore* of the American Association for the Advancement of Science; and the committee will act together with the secretary of the Smithsonian Institution as member *ex officio*. The right is reserved to award no prize if, in the judgment of the committee, no contribution is offered of sufficient merit to warrant an award. An advisory committee of not more than three European men of science may be added at the discretion of the committee of award.

If no disposition be made of the first prize at the time now announced the Institution may continue it until a later date, should it be made evident that important investigations relative to its object are in progress, the results of which it is intended to offer in competition for the prize. The Smithsonian Institution reserves the right to limit or modify the conditions for this prize after December 1, 1894, should it be found necessary. Should any of the minor prizes not be awarded to papers sent in before July 1, 1894, the said prizes will be withdrawn from competition.

A principal motive for offering these prizes is to call attention to the Hodgkins fund and the purposes for which it exists, and accordingly this circular is sent to the principal universities, and to all learned societies known to the Institution, as well as to representative men of science in every nation. Suggestions and recommendations in regard to the most effective application of this fund are invited.

It is probable that special grants of money may be made to specialists engaged in original investigation upon atmospheric air and its properties. Applications for grants of this nature should have the indorsement of some recognized academy of sciences or other institution of learning, and should be accompanied by evidences of the capacity of the applicant in the form of at least one memoir already published by him, based upon original investigation.

To prevent misapprehension of the founder's wishes it is repeated that the discoveries or applications proper to be brought to the consideration of the committee of award may be in the field of any science or any art without restriction; provided only that they have to do with "the nature and properties of atmospheric air in connection with the welfare of man."

Information of any kind desired by persons intending to become competitors will be furnished on application.

All communications in regard to the Hodgkins fund, the Hodgkins prizes, the Hodgkins medals, and the Hodgkins fund publications, or applications for grants of money, should be addressed to S. P. Langley, Secretary of the Smithsonian Institution, Washington, U. S. A.

[SEAL.] S. P. LANGLEY,

Secretary of the Smithsonian Institution.

Washington, March 31, 1893.

Some desire being expressed for a more explicit declaration of the scope of the investigations permitted by the Hodgkins foundation, the following supplementary circular was issued in April, 1893, in further explanation of the purport of the donor's intentions:

SMITHSONIAN INSTITUTION.

HODGKINS PRIZES.

WASHINGTON, *April, 1893.*

In answer to inquiries and in further explanation of statements made in the Hodgkins circular, it may be added that any branch of natural science may offer a subject of discussion for the Hodgkins prizes, where this subject is related to the study of the atmosphere in connection with the welfare of man.

Thus, the anthropologist may consider the history of man as affected by climate through the atmosphere; the geologist may study in this special connection the crust of the earth, whose constituents and whose form are largely modified by atmospheric influences; the botanist, the atmospheric relations of the life of the plant; the electrician, the atmospheric electricity; the mathematician and physicist, problems of aërodynamics in their utilitarian application; and so on through the circle of the natural sciences, both biological and physical, of which there is perhaps not one which is necessarily excluded.

In explanation of the donor's wishes, which the Institution desires scrupulously to observe, it may be added that Mr. Hodgkins illus-

trated the catholicity of his plan by citing the experiments of Franklin in atmospheric electricity, and the work of the late Paul Bert upon the relations of the atmosphere to life, as subjects for research, which, in his own view, might be properly considered in this relationship.

While the wide range of the subjects which the founder's purpose makes admissible can not be too clearly stated, it is equally important to emphasize the fact that the prizes in the different classes can be awarded only in recognition of distinguished merit.

S. P. LANGLEY,
Secretary

Numerous applications, which are referred to the advisory committee for consideration, have already been made for grants from the fund to aid original investigations upon the nature of atmospheric air and its properties. Two have been approved, a grant of $500 having been made to Dr. O. Lummer and Dr. E. Pringsheim, members of the Physical Institute of the Berlin University, for researches on the determination of an exact measure of the cooling of gases while expanding, with a view to revising the value of that most important constant which is technically termed the "gamma" function. Drs. Lummer and Pringsheim were recommended for this work by the eminent Professor Dr. H. von Helmholtz, of Berlin.

A second grant of $1,000 has been made to Dr. J. S. Billings, U. S. A., Army Medical Museum, Washington, and to Dr. Weir Mitchell, of Philadelphia, for an investigation into the nature of the peculiar substances of organic origin contained in the air expired by human beings, with a specific reference to the practical application of the results obtained to the problem of ventilation for inhabited rooms.

It is the intention that all applications for special grants shall be thoroughly weighed by the committee first appointed, one of whose functions it is to advise upon matters of this nature. They will then be referred to the second, or committee of adjudication, for final action, which shall be reached only after a comparative estimate of the value of the researches proposed, and their relation to the object for which the Hodgkins fund was established.

Numerous papers have already been submitted in competition for the prizes, all of which will be carefully examined and passed upon by the committees before a final decision as to their merit can be reached.

The Secretary has under advisement the designs for the medal established in connection with the Hodgkins competition, and which it has been determined to award annually or biennially.

The death of Mr. Hodgkins occurred on the 25th of November, 1892, when he had reached the age of nearly 90 years. In this event the Institution lost not only a generous benefactor but a friend whose counsel was rendered valuable by the breadth of his views no less than by the earnestness of his purpose to enlarge the domain of practical science in its relation to the welfare of man.

MISCELLANEOUS.

The Naples table.—In the spring of 1893 a petition, signed by nearly 200 working biologists, who represented some eighty universities and scientific institutions, was presented to me, asking that a table be maintained by the Smithsonian Institution at the Naples Zoological Station, for the benefit of American investigators.

This step, urged by so large a number of representative scientific men, having been duly considered and favorably decided upon, the following letter was addressed to Dr. C. W. Stiles, of the American Morphological Society, through whom the petition referred to reached me:

SMITHSONIAN INSTITUTION,
Washington, April 7, 1893.

DEAR SIR: I have given careful consideration to the petitions and papers presented by you, and I have decided, in behalf of the Smithsonian Institution, to rent a table at the Naples Zoological Station for three years, and have already taken steps to secure it.

I shall be glad to be able to learn the opinions of the representative biologists of the United States in regard to the best administration of this table, and I shall esteem it a favor if, through your mediation, an advisory committee of four persons may be formed, one to be nominated by the president of the National Academy of Sciences, one by the president of the American Society of Naturalists, one by the president of the Morphological Society, and one by the president of the Association of American Anatomists, with the understanding that I may, if need arise, feel at liberty to ask their counsel in regard to the regulations for the use of the table, or as to the merits of applicants for it.

The table will be known as the Smithsonian table. Publications resulting from its use will bear the name of the Smithsonian Institution, and such of them as are of sufficient importance will probably be printed in the Smithsonian Contributions to Knowledge.

While the exact conditions will be determined later, I may say, subject to better advices, that it seems to me now that applications for the use of the table should be made to the Secretary of the Institution, who will probably desire to feel authorized to consult the above-mentioned committee concerning them whenever in his judgment occasion arises for doing so.

If this meets your approval will you kindly communicate to the president of each of the societies named my request that he nominate a member of the advisory committee in question.

Very respectfully, yours,

S. P. LANGLEY,
Secretary.

DR. C. W. STILES.

Four members of an advisory committee were nominated in accordance with my request, as follows:

Maj. John S. Billings, U. S. A., nominated by Prof. O. C. Marsh, president of the National Academy of Sciences.

E. B. Wilson, PH. D., professor of zoology, Columbia University, nominated by Prof. Chittenden, president of the Society of American Naturalists.

C. W. Stiles, PH. D., zoologist, Bureau of Animal Industry, U. S. Department of Agriculture, nominated by Prof. C. O. Whitman, president of the American Morphological Society.

John A. Ryder, PH. D., professor of embryology, University of Pennsylvania, nominated by Prof. Allen, president of the Association of American Anatomists.

These nominations having been approved, I designated Dr. J. S. Billings, U. S. A., chairman and Dr. C. W. Stiles secretary of the committee.

Satisfactory conditions as to the occupancy of the table were arranged with Dr. Dohrn, the director of the station at Naples, and the following contract was duly signed and completed:

[Translation.]

CONTRACT.

1. The director, Dr. A. Dohrn, places a study table in the laboratories of the Zoological Station at Naples at the disposition of the Smithsonian Institution under the following conditions and on the terms stated in article 11 of this contract:

2. The table will be prepared for the occupancy of the student designated by the Smithsonian Institution within one week from the time the administration shall have been advised of his arrival.

3. The table must be supplied with the objects enumerated below, as follows:

(*a*) The principal chemical reagents;
(*b*) Instruments ordinarily needed in anatomy and microscopy;
(*c*) Implements for drawing.

The laboratories will be found provided with the more complicated instruments and apparatus which are commonly used; these, however, will be provided only in duplicate or in triplicate, while they are to serve for the general use. The station does not provide optical instruments for the tables, it being understood that those who come there to work are to furnish their own.

4. The table is supplied with a sufficient number of small aquaria with flowing water, to serve for any experiments which the student may need to make.

5. The animals which are the object of the research, will be renewed as often as possible, and according to the student's needs. It will also be practicable to have material prepared and preserved in known ways, in order that the studies commenced at Naples may be continued elsewhere.

6. The great aquarium attached to the Zoological Station will be open *gratis* to the occupant of the table, either for his entertainment or for his studies upon animal habits.

7. The library of the Zoological Station is in a hall adjacent to the laboratories, and is accessible to the occupant of the table, who may use it as a reading or a writing room.

8. The laboratories will be open at 7 o'clock in the morning in summer and 8 o'clock in winter. In exceptional cases, other arrangements may be made with the administration, though the employés are not obliged to open the laboratories before the given hour. From June 20 to August 20 the laboratories will be closed.

9. The occupant of the table will have the right to share in the fishing expeditions sent out from the station, as well as to learn the different methods in use.

10. Injuries to the instruments and utensils caused by the occupant of the table, will be at the cost of the administration, so long as the amount does not exceed 20 francs.

11. The present contract is for the term of three years, and the Smithsonian Institution promises to pay Dr. Anton Dohrn, the Director of the Zoological Station, yearly in advance, the sum of 2,500 francs, in gold, for the rent of the table in the laboratories of the Zoological Station.

Signed in duplicate,
Washington, June 9, 1893.

S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Naples, May 16, 1893.

Professor Dr. ANTON DOHRN,
Director of the Zoological Station of Naples.

Numerous applications for the occupancy of the table have been received, but at the close of the fiscal year sufficient consideration had not been given them to render it possible to make any definite assignment.

With a desire for the information necessary to a right administration of the affairs of the table, I have requested that all applications shall be accompanied by credentials showing the qualifications of the candidate to carry on original investigations in some field for which especial facilities are offered at the Naples Station. These credentials are to be accompanied by a scientific history of the candidate, together with a list of such original papers as he may have published.

Those appointed to the table will be expected to make a report at the end of their term of occupation, or, in case of a long residence at the station, to submit such a report to the Institution every three months.

Seal of the Institution.—It having been found advisable that the Institution should have a new seal, a device was prepared by Mr. St. Gaudens, the eminent sculptor, whose æsthetic value, as compared with the one it replaced, is incontestable. One of the first uses of this seal was to affix it to the circular concerning the Hodgkins gift, which has just been referred to. Its use as the seal of the Institution was formally recognized by the resolution of the Regents of January 25, 1893.

Lunar photography.—I have been interested for a considerable time in the possibility of preparing a chart of the moon by photography, which would enable geologists and selenographers to study its surface in their cabinets with all the details before them which astronomers have at command in the use of the most powerful telescopes.

Such a plan would have seemed chimerical a few years ago, and it is still surrounded with difficulties, but it is probable that within a comparatively few years it may be successfully carried out. No definite scale has been adopted, but it is desirable that the disk thus presented

should approximate in size one two-millionth of the lunar diameter; but while photographs have been made on this scale, I do not think that any of them show detail which may not be given on a smaller one.

I have been favored with the cooperation and interest in this work of the directors of the Harvard College Observatory, of the Lick Observatory, and others, who in response to a letter addressed to them on February 10, 1893, have obliged me with many valuable suggestions. This important work is still under advisement.

Delegates to universities and learned societies.—The Smithsonian Institution is not infrequently invited to send representatives to special celebrations instituted by learned societies or universities with which it is in correspondence both in this country and abroad. Whenever practicable, special delegates have been designated by the Secretary to represent the Institution on such occasions.

Dr. James C. Welling, president of the Columbian University and Regent of the Smithsonian Institution, who was proceeding abroad as a Commissioner of the United States to the Exposition at Madrid in 1892, was appointed delegate of the Smithsonian Institution to the Tercentenary celebration of the founding of Trinity College of the University of Dublin, which took place on July 5–8, 1892.

Dr. George Vasey, botanist of the U. S. Department of Agriculture and honorary curator of the department of botany in the U. S. National Museum, represented the Smithsonian Institution and the National Museum at the Botanical Congress, Geneva, on the occasion of the Columbian festivities, from the 4th to the 12th of September, 1892.

At the celebration of the one hundred and fiftieth anniversary of the founding of the American Philosophical Society of Philadelphia, from May 22 to May 26, 1893, the Smithsonian Institution was represented by Prof. William C. Winlock, Assistant in charge of office; Dr. Goode, the Assistant Secretary, having been unable to attend.

Assignment of Rooms.—A room is still reserved in the basement for the use of the officers of the U. S. Coast and Geodetic Survey for pendulum experiments.

The American Historical Association.—The annual report of the American Historical Association was on February 27, 1893, communicated to Congress in accordance with the act approved January 4, 1889, and the usual public document number of 1,900 copies was ordered printed.

Stereotype plates and cuts.—The collection of stereotype plates of the Smithsonian and Museum, and of engravers' wood cuts and process plates is now so large that its proper cataloguing and storage has called for serious attention. It has always been the policy of the Institution to permit the use of these plates by publishers under reasonable conditions, and the requests for electrotype copies of cuts have grown more numerous. The original cuts are placed in the hands of

an engraver and electrotype copies are furnished at very small cost, the expense being met by the applicant.

Special Smithsonian correspondent in Paris.—M. C. Reinwald & Co., 15 rue des Saints-Pères, Paris, were designated, on June 6, 1893, as special correspondents of the Smithsonian Institution, through whom commissions can be conveniently attended to. I should add that no compensation is attached to this agency.

Russian Physico-Chemical Society.—I deem it not inappropriate to give the following letter received June 29, 1892, from the Russian Physico-Chemical Society:

ST. PETERSBURG, *May 31, 1892.*

Russian Phyisco-Chemical Society University to the Smithsonian Institution at Washington:

The universal science reposes on the brotherhood of nations. The United States of America in sending bread to the Russian people in time of scarcity and need gave the most affecting instance of brotherly feeling. The Russian chemists who devote themselves to the service of universal science, at their meeting of the 7/19 of May decided to ask their brethren of the Smithsonian Institute, to transmit the expression of their sincere thanks to all persons or institutions who contributed to the fulfillment of this brotherly aid.

President D. MENDELEEFF.
Secretary D. KONOWALOW.

A copy of this letter was communicated to the chairman of the Russian Famine Relief Committee and to the public press.

Correspondence.—Minor changes have been made in the methods of handling correspondence, with a view to disposing of all letters with the greatest dispatch compatible with the character of the work, and the number of clerks that can be assigned to such duties. During the preceding year a plan was adopted of separating the files in the Secretary's office according to the different branches of the work, independent files being assigned to the Secretary's correspondence concerning the Smithsonian routine proper, the observatory, the museum, the park, etc.; and with each file, separate press-copy books. The files have been designated as follows:

1. Smithsonian proper.
2. The National Museum.
4. The Bureau of Ethnology.
5. The Zoological Park.
6. The Astro-physical Observatory.
11. Assistant in charge.
20. Aerodynamics.
25. Hodgkins fund.

A card index was begun on January 1, 1893, for both letters received and letters written, to facilitate reference to the various files, and this index will be extended back to all letters since January 1, 1892, as opportunity offers.

Each letter of importance is registered as I have described in previous reports, and its course is traced until it is finally disposed of. In addition to letters registered, many are forwarded directly to the Museum, the Bureau of Ethnology, the Zoological Park, the Bureau of International Exchanges, etc., for disposition. Many others, concerning publications, are sent directly to the document room there to be filed and accounted for. Referring now only to letters that are registered in the Secretary's office, 3,184 entries were made for the fiscal year 1892–'93.

A further change in treating correspondence has gradually been forced upon the Secretary, and with the object of obviating the necessity of giving so much of his time to matters of purely clerical routine, a decision was finally reached, to delegate authority to the Assistant in charge of office, to the acting Curator in charge of the Museum, and to the Librarian, to sign routine letters bearing exclusively upon designated classes of correspondence. This has relieved the Secretary of personally attending to correspondence of this class, without impairing his proper supervision of official business.

THE NATIONAL MUSEUM.

The Museum of the Smithsonian Institution, the nucleus of which was Smithson's cabinet of minerals, was formed in part, and for a time entirely maintained, at the expense of the Smithson fund. Subsequently, at the bidding of Congress, the Institution assumed charge of the so-called "National Cabinet of Curiosities," which included the collections of the United States exploring expedition; the collections of the National Institute founded in 1840, and numerous other objects and collections which had accumulated under the charge of the Commissioner of Patents. For thirty-five years these two series of collections have been housed and cared for conjointly, and form the nucleus of what is now known as the National Museum.

Each year since 1858 Congress has appropriated a certain sum of money for the maintenance of the National Museum, but up to this time it has not made any special provision for the improvement of the collections by purchase, while it is becoming evident that those received by gift or from other Government sources, though of considerable extent, are of rapidly diminishing consequence, since these things are attaining each year a higher and higher market value, and are tending to be commanded only by purchase.

In respect of this provision for purchase, the National Museum stands at the foot of all American museums, being surpassed even by every municipal museum of note with which I am acquainted.* The disad-

*The American Museum of Natural History, for example, expended $23,552.89 for additions to its natural history collections during 1892, while the National Museum, which is of very much wider scope, expended only $5,769.75 during the fiscal year 1892–'93, for collections of all kinds.

vantage in which it stands, when compared with what are now its competitors in the national collections of the leading countries of Europe, has grown painfully obvious. Important collections made in this country of the objects illustrating the vanishing life of its own native races of men and animals—collections which can never be made again, and never be replaced—are being permanently withdrawn to enrich the museums of Europe. This has already gone so far that it is necessary in order to study the past life of our own Mississippi Valley to go to England, while for that of southern Alaska we must go to Berlin, and for the Californian coast we must go to Paris, and so on. It is already then, in European capitals more than in our own, that we have to go for some of the most important studies of our native races; and at the present rate, within a few more years, when the American collector has nothing more left to gather and to sell abroad, it will be in Europe and not in America that the student of past American history must seek for nearly everything that most fully illustrates the ancient life and peoples of the American continent.

This is an exceedingly regrettable circumstance and one which I sincerely hope the National Legislature will be disposed to modify. I may remark in this connection that the National Museum is in danger of forfeiting its proper status also on account of the competition of private collections. With the increase of wealth in the country the desire for the establishment of museums in various cities has been realized and the amount spent for objects in many of them is far greater than the National Museum has ever had at its disposal. While the National Museum has always desired to cooperate fully with private establishments of like nature, it is felt that the scientific and educational collection of the Government should be in nowise inferior.

During the past year the Museum has been, as hitherto, under the charge of Dr. G. Brown Goode, the Assistant Secretary of the Institution. Mr. Frederick W. True was designated by me curator-in-charge, and has assumed the general management of the Museum at different times during the absence of the Assistant Secretary.

A full report upon the operations of the Museum has been prepared by Dr. Goode, and will form a separate volume, of which an abstract is given here later.

The Museum has been engrossed during the year in completing the preparations for the exhibits at the World's Columbian Exposition, and this work caused the practical suspension of many regular operations. The exhibits were ready at the appointed time and were installed in the Government building in the Exposition by the curators of the Museum, under the direction of the Assistant Secretary, who was the representative of the Institution on the Government board.

A statement regarding the exhibits of the Museum will be found in the report of the Assistant Secretary.

In connection with this work mention should be made of the Colum-

bian Historical Exposition held in Madrid in the fall and winter of 1892. This Exposition was a part of the very extensive celebration of the four hundredth anniversary of the sailing of Columbus, held in the various cities of Spain under the direction of the Spanish Government. A commission was appointed by the President to represent the United States, consisting of Rear Admiral Luce, U. S. N., Dr. J. C. Welling, one of the regents of this Institution,* and Mr. Goode, its Assistant Secretary, and a liberal appropriation made for the expenses of transportation and maintenance of the exhibits. Extensive collections were sent by the Smithsonian Institution, taken from its own collections and borrowed from its collaborators and correspondents. They were ethnological, archeological, and historical, and were supplemented by other collections sent by the University of Pennsylvania, the Bureau of American Republics, and the Hemenway Expedition. The exhibition in Madrid was as a successful one, and the exhibit of the United States was highly appreciated by the Spanish Government, and led to its extraordinarily generous participation in the subsequent celebration in Chicago. Gold medals were awarded to the Smithsonian Institution, to the Museum, and the Bureau of Ethnology.

The Museum building has been visited by a larger number of persons during the past year than ever before, the total number exceeding 300,000. This growing interest in the collections on the part of the public, is a gratifying circumstance, and leads to the belief that the care bestowed upon the exhibition series is not unappreciated.

On account of the crowded condition of the exhibition halls, the effective display of many of the collections of the Museum is prevented. The proper lighting of the cases is interfered with and the arrangement of the specimens is necessarily less systematic than is desirable.

The Museum has continued to distribute to educational establishments throughout the country such collections of duplicate natural-history specimens as it has been found practicable to prepare. Somewhat more than 13,000 specimens have been sent out during the year. These, however, have been far from sufficient to meet the demands of applicants and numerous requests remain unacted upon. I regard this distribution of specimens as one of the most important operations of the Museum, and one on which much more time and money could be profitably spent. With the resources available it has been impossible to prepare collections in more than a few lines, and these have all been more or less imperfect. The high schools of the country, to which such collections would be of much value, can not at present be supplied.

My attention has been called by the Assistant Secretary to the inadequate size of the editions of the publications of the Museum. It is not at present possible to supply all the larger libraries of the world, and the majority of the smaller ones, in many of which they would be of

* Dr. Welling was recalled by official business after reaching London, and was replaced by Dr. Daniel G. Brinton, of the University of Pennsylvania.

high utility, are entirely unprovided. Individuals do not receive the volumes at all, but only such papers extracted from them as relate to the scientific work in which they are immediately concerned. It is much to be desired that larger editions should be provided for.

During the year two volumes of the Proceedings and one complete number and parts of another number of the Bulletin were published.

The Museum has been benefited, as in previous years, by the co-operation of the several Departments and Bureaus of the Government. Special mention should be made in this connection of the many courtesies received from the consular service of the Department of State. The Quartermaster's Department of the Army has assisted materially by providing transportation for bulky collections coming to the National Museum from remote localities. The Museum has further been able to avail itself of the services of officials of the Navy Department, Department of Agriculture, the U. S. Geological Survey, and U. S. Fish Commission, who have acted in the capacity of honorary curators.

BUREAU OF ETHNOLOGY.

The researches of the Bureau of Ethnology relating to the American Indians were continued during the year in accordance with law, under the direction of Maj. J. W. Powell, who also directed the work of the U. S. Geological Survey.

As during previous years the work of the Bureau has been conducted with special reference to the American Indians in their primitive condition, with a view of securing the largest possible amount of information, both in the form of records for print and in the form of material objects for preservation and future study in the National Museum. Thus extensive collections are made annually, and the value of these collections is greatly enhanced by reason of the full notes always prepared and the extended publications sometimes made by the collectors.

The non-material collections of data relating directly to the native Americans, to the distribution of tribes, to their habits and customs, to their arts, languages, institutions, and beliefs, are also abundant and, it is believed, of permanent value. Detailed information on these subjects is published in three series of reports additional to the abstracts appearing in the Report of the Secretary of the Smithsonian Institution. The thirty volumes already published form a rich storehouse of facts relating to our native races. Four volumes were added to this library during the year.

One of the most interesting questions ever raised concerning the early peoples of this country related to the artificial mounds scattered abundantly over the Mississippi Valley and with less abundance over most of our territory. Many investigators have given attention to these works of a vanished race; and it came to be a general opinion

that the builders of the mounds were a distinct people ante-dating the native races found in possession of the land on the advent of the Europeans. Within the last five years extended surveys of the mound territory have been made by collaborators of the Bureau under immediate instructions from the Director and by Dr. Cyrus Thomas. An elaborate report on this subject has been prepared during the year and is now in press. It is the united opinion of the officers of the Bureau that this document contains the solution to the mystery of the mounds; very greatly to the surprise of the investigators who began the work, they have been led to believe that the mounds and the art products contained therein are in no wise distinct from the works of the modern Indians, and that the distribution of tribes can now be studied from the mounds themselves as well as from other aboriginal records.

The work of the Bureau on Archeology or prehistoric arts has been conducted with energy and exceptional success. Until recently many of the leading students of American antiquities were Europeans; and thus it happened that the classification of American art products was to a large extent an imported one, corresponding to foreign generalizations and ideals rather than to any indigenous standard. Thus a history of succession of peoples, representing increasing grades of culture, has been wrought out. As will be seen from the reports of the Director and collaborators of the Bureau, however, an indigenous classification has been also developed by it, and it has been shown to be probable that the objects supposed to represent the series of culture stages are in most cases at least the handiwork of single tribes during the same epoch. These researches were conducted chiefly by Prof. W. H. Holmes, with the assistance of Messrs. Fowke and Dinwiddie. If these important results obtain general acceptance, the effect will be to shorten the earlier estimates of the antiquity of man on this continent, and in this respect it will be observed that they are coincident with those flowing from the mound researches.

Important investigations concerning the beliefs of the Indians of different parts of the country have been conducted during the year, notably by Mrs. M. C. Stevenson and Mr. F. H. Cushing among the Zuñis, and Dr. Hoffman among the remnants of the Lake Superior tribes. An elaborate memoir by the first-named collaborator was sent to press during the year.

The principal work relating to the sociology or institutions of the aborigines was that of continuing the preparation of a tribal synonymy or dictionary of tribal names, including not only those names applied by white men, but the names current among the Indians themselves. Connected with this work is a detailed study of the literature relating to the Indian languages by Mr. James Constantine Pilling. The results of this study form a bibliography which has already come to be recognized as a standard by the bibliographic students of the world.

An important line of investigation related to the means of interchanging ideas among our native races, including gesture, speech, and picture writing, as well as spoken language. The primitive modes of expression by means of gestures or pantomime and by means of glyphs or pictures are held by students as of special interest, in that they represent the beginnings of language. These modes of conveying ideas have received much attention by collaborators of the Bureau, notably Col. Garrick Mallery. An elaborate memoir on the "Picture writing of the American Indians" is incorporated in the tenth annual report of the Bureau. This memoir is a practically exhaustive monograph on the subject to which it relates; the illustrations, which number nearly fourteen hundred, represent the aboriginal picture writing of all portions of the country with fidelity, while the meanings of the glyphs are interpreted and discussed in detail in the text. A large body of material relating to the sign language of the aborigines has been collected, and during the year progress was made in arranging this material for publication. In no other part of the world have the opportunities for collecting detailed information concerning primitive modes of expression been so favorable as in North America; and it is thought that these reports prepared by collaborators of the Bureau, will serve at once as a record of past and passing races and a basis for philological researches in other countries.

The spoken languages of various tribes of Indians were studied and recorded. One of the most extensive aboriginal linguistic families was the Siouan, including the Indians of the northern plains from the Rocky Mountains to the Mississippi, and from the Saskatchewan nearly to the Red River of the South. One of the publications of the year was a "Dakota-English Dictionary," in which the language of the best-known division of the Siouan family is made accessible to students, this work, begun by the late Dr. Riggs, being completed by Mr. J. Owen Dorsey, a linguist especially familiar with the languages of this stock. The dictionary forms a quarto volume of nearly seven hundred pages. The language of the Biloxi Indians of Louisiana was also investigated during the year by Mr. Dorsey; Dr. Gatschet made a detailed study of the Peoria, Shawnee, Arapaho, and Cheyenne languages in Indian Territory, the work on the Peoria being complete with respect to both vocabulary and grammar.

The Iroquoian languages also were the subject of study by Mr. J. N. B. Hewitt. Unwritten language is one of the most evanescent of human characters; already the languages of many of our native tribes have entirely disappeared, save for a few greatly modified terms preserved as geographic names; and it seems especially important to record the rapidly changing native languages thus far remaining. Some of the vocabularies and grammars collected by the Bureau were derived from half a dozen or fewer individuals who alone represent their tribe; in one case (the Chinooken) the language was preserved through infor-

mation obtained from the last representative of his people. A large part of the publications of the Bureau relate to aboriginal languages; yet the more or less fragmentary material, incomplete but constantly growing, relating to this subject is still more voluminous; and students of linguistics throughout the world are to be congratulated on the existence of this rich storehouse of material collected through the labors of the Smithsonian Institution and of the Bureau of Ethnology.

In addition to the researches in field and office several collaborators of the Bureau were employed during the closing months of the year in preparing an ethnologic exhibit for the World's Columbian Exposition at Chicago. This exhibit was completed and installed duly; and it is a source of gratification to be able to say that it proves constantly attractive to visitors, and it is believed to have been also highly instructive.

The details of the work of the Bureau are set forth in the report of the Director, Maj. J. W. Powell, which forms the accompanying Appendix II.

SMITHSONIAN INTERNATIONAL EXCHANGE SERVICE.

The International Exchange Service has always been intimately connected with the parent institution, which has until lately aided it largely from its private funds, and which still aids it by giving it rooms rent free and in other ways.

It may be said to be at present upon as satisfactory a basis as it seems possible to place it with the appropriations that are now made by Congress.

As an illustration of the extent of this special part of the Institution's activities, it may be stated that it has now about 24,000 active correspondents, of whom 14,000 are in Europe, 200 in Africa, 500 in Australia, and about 9,000 in the various countries of the Western Hemisphere. In the course of this work the Institution has gathered at Washington an immense collection of books, found nowhere else to so great an extent, bearing chiefly upon discovery and invention, which, with others, now occupy nearly 300,000 titles. These are deposited temporarily with the National Library at the Capitol.

The details of the operations of the service are to be found in the curator's report appended. Improvements in the service are needed in an increase in the clerical force for office work, or rather a return to the number employed in 1891–'92. There is need also for securing a more prompt dispatch and distribution of packages abroad, which can only be brought about by an increase of appropriation.

The United States Government is under treaty obligation to maintain an exchange service with ten foreign countries, and with France, England, and Germany a special exchange arrangement is in existence. In the two latter countries, where there are paid agents of the Institution, and in other countries where official exchange bureaus have been established the transmission of publications, while somewhat slow, is generally efficient. In other cases, however, the present arrangement is by

no means satisfactory, and it seems desirable, either through diplomatic channels or through a special representative of the Institution sent abroad, to secure the interest and cooperation of the foreign governments and the learned societies where no official exchange bureau has been established.

The greater part of the expense of the service is now met by direct appropriation for the purpose by Congress to the Smithsonian Institution. A part of the expense is also met by appropriations to different Government bureaus from their contingent funds, the Regents of the Institution having decided to make a charge to all Government bureaus of 5 cents per pound weight for the transmission of their publications or for the publications received for them from abroad.

Special acknowledgments are due to the Treasury Department for designating one of its officers at the New York custom-house to receive and transmit to Washington the international exchange cases addressed to the Institution, and I may in this connection again quote the remark made by Prof. Henry in his report for 1854:

> There is, therefore, no port to which the Smithsonian packages are shipped where duties are charged on them, a certified invoice of contents by the Secretary being sufficient to pass them through the custom-house free of duty. On the other hand, all packages addressed to the Institution arriving at the ports of the United States are admitted without detention, duty free.

By referring to the report of the curator, in the appendix, it will be seen that over 100 tons of books passed through the exchange office during the fiscal year 1892–'93, and while the service is used almost exclusively for the transmission of printed matter of a scientific nature, natural history specimens, having no commercial value, are occasionally transmitted under special permission, when they can not be conveniently forwarded by the ordinary means of conveyance.

The expenditures for the year have been $18,518.25, of which $17,000 were appropriated by Congress, $1,396.64 were paid by Government bureaus, $87.35 by State institutions and others, leaving a deficiency of $34.26.

The amount estimated for the exchange bureau for the year 1893–'94 was $23,000, a sum which it was hoped would render it unnecessary to call upon the different Government Departments for a part of the expense attending the transmission of their publications, and would also render it possible to put into effect a second treaty entered into by the United States and other countries at the same time as the treaty referred to above, by which each country undertook to distribute its parliamentary proceedings immediately when issued. On account of a lack of appropriations for this purpose no action has yet been taken by the United States for carrying out this latter agreement.

In my report for 1890 I stated that there had been expended from the Smithsonian fund for the support of the international exchange system, in the interests and by the authority of the National Government,

$38,141.01 in excess of appropriations, advanced from January 1, 1868, to June 30, 1886, for the exchange of official Government documents, and $7,034.81 in excess of appropriations from July 1, 1886, to June 30, 1889, advanced for the purpose of carrying out a convention entered into by the United States, or an aggregate of $45,175.82, which has been paid from the private fund of James Smithson, for purely governmental expenses. This has still to be reimbursed to the Institution.

A memorandum in regard to the matter was duly transmitted to a member of the Board of Regents, in the House of Representatives, for the purpose of taking the necessary steps to procure a return by Congress to the Smithsonian fund of this last-mentioned sum, namely, $45,175.82, but I am not aware that action has been taken upon it.

NATIONAL ZOOLOGICAL PARK.

It should always be remembered that the establishment* of the National Zoological Park resulted largely from a desire to keep from extinction species of American animals, several of which are now upon the point of vanishing from the face of the earth, and will vanish forever if something is not done at once to preserve them.

The paramount need of preserving these races by immediate legislative action, if they are to be preserved at all, the great and constantly increasing difficulty of obtaining specimens of some of them, the little that is known of their habits, and the impossibility of ever learning more, unless some immediate measures are taken to make careful observation possible, render it exceedingly desirable that such measures should be taken officially, and no more economical or effective plan could be devised than that of providing a moderate extent of land, near the seat of Government, duly protected and guarded, where such animals as could be secured might be kept in a state as near as possible to that to which they had been accustomed, and under conditions where they might be expected to breed, and continue their species, as they are known not to do in ordinary menageries.

It was not indeed thought that any efficient check could be given to the final extinction of these animals solely by such a limited number as could be thus preserved, but it was considered that their presence here at the Capital would be not only useful as regarded the number saved, but as a constant object lesson, under the eyes of the legislature, and in this way, a most important adjunct to the larger reservations like the Yellowstone Park; while it was evident that opportunity could thus be afforded to study and observe their habits and characteristics, where they were under the eyes of the numerous naturalists in the Government service, in a more satisfactory manner than would be possible in a remote wilderness.

The act providing for the purchase and creation of the National Zoological Park introduced also a subordinate feature, that of the

* Reference may be made to the following pages in the Annual Reports of the Smithsonian Institution: Report for 1888, p. 42; for 1889, p. 27; for 1890, p. 34, and Secretary's Report for 1891, p. 21, and 1892, p. 28.

recreation of the people, but by placing one-half of the expense of purchase and maintenance upon the taxpayers of the District, Congress in fact, though presumably not in intent, made this subordinate feature predominant in a plan whose inception arose in a simpler and more utilitarian idea.

This predominance arose from the natural wish of the local taxpayer to receive entertainment for his money and not to spend it for objects of remote and national importance. This demand must be admitted to have been but reasonable, from the point of view of residents of the District, and it made itself felt through Congress in many ways, if not through the terms of formal legislation.

Those to whom was delegated the power of carrying out the mandates of Congress were thus confronted by a different task from that originally contemplated: by one in some way not consonant with it, and by a far more expensive one. In place, for instance, of the large inexpensive paddocks for inclosing and sheltering the animals under the conditions of wild life, and secluding them with the aim of enabling them to increase in the undisturbed retirement necessary, must be substituted comparatively expensive buildings, with the opposite aim of exhibiting the animals obtained. A system of roadways that should afford the public access to all parts of the park where animals are kept had to be devised, and in ways too numerous for detail the necessity was imposed of forming the National Zoological Park more on the model of an ordinary zoological garden than of the first large and simple idea.

It was impossible to do this within the sum calculated to carry out the original plans, but no more has been granted. What has been done has been done, then, incompletely, though with an extremely economical expenditure, and it is perhaps a matter of congratulation that it has been possible to do so much with so limited an amount.

The appropriation made for the National Zoological Park by the sundry civil bill passed August 5, 1892, was in the following terms:

For continuing the construction of roads, walks, bridges, water supply, sewerage and drainage, and for grading, planting, and otherwise improving the grounds, erecting and repairing buildings and inclosures for the animals, and for administrative purposes, care, subsistence, and transportation of animals, including salaries and compensation of all necessary employés, and general incidental expenses not otherwise provided for, fifty thousand dollars, one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and a report in detail of the expenses of the National Zoological Park shall be made to Congress at the beginning of each regular session.

The previous year had fully demonstrated that the park successfully fulfilled one of the purposes for which it was created—that of the "instruction and recreation of the people." After having done all that lay in my power for the promotion of the primary objects of the park*

* A full statement of the number and condition of these animals will be found in the report of the acting manager. It may be stated here, however, that indigenous wild animals constitute at present a large majority of the whole.

it became necessary to further, as far as possible, and in the same connection, the recreation of the public. To this end, and to that of convenience and safety, the roadways have been widened and extended, footways have been placed on the bridge, the access to the principal animal house and to the principal outdoor cages has been improved, and all inclosures considered unsafe have been properly strengthened or defended.

Since the Rock Creek electric railway has been in operation many passengers by that route enter the park by the western entrance upon Connecticut avenue extended. More than 2,000 persons have sometimes entered here during a single day. This has made it necessary to extend the main road through the park to that entrance, which has been done on the lines indicated by Mr. F. L. Olmsted, and gives a driveway through the most beautiful part of the park. The funds at the disposal of the park were insufficient to complete this road in a permanent manner. As soon as practicable it should be macadamized and made equal to the suburban roads with which it communicates.

It is necessary to emphasize the fact that the number of visitors to the park so far exceeds all the earlier calculations that unexpected outlays have become necessary. A wider sidewalk of a permanent character is needed from the Quarry road entrance to that at Connecticut avenue. A temporary wooden walk has been placed to the animal house from the first-named point, but is far too narrow for the crowds entering there every Sunday and holiday, while no sidewalk exists from the western entrance of the park.

The bridge near the Quarry road entrance has proved quite insufficient for the crowds of carriages and foot passengers that throng it upon every holiday. It was and still is greatly to be regretted that under the actual appropriations a larger and more tasteful structure could not have been built at this point; it was erected under the necessity of getting visitors across the river in some way, and is in a form entirely unsatisfactory to those who, under such necessity, designed it. Some relief has been given during the year by the addition of narrow footways on either side of the driveway. These are quite too narrow, but are all that the present structure will allow compatible with safety. It may be found necessary to build a footbridge at a point higher up the stream to somewhat relieve the pressure at this point.

The addition to the principal animal house mentioned in last year's report has been completed and fully occupied. It is merely a frame shed built in as cheap a manner as is consistent with safety, and warmth, and it appears incongruous when compared with the solid stone structure of which it forms an annex. The original design of constructing this entire building of stone should not be abandoned. It is already found to be insufficient for the needs of the park, and must at no distant day be further extended. It will be necessary hereafter to bear in mind that the cages for animals must be larger and confined

usually to but one side of the building. The throngs of visitors are now sometimes so great that it is impossible for them to view the animals properly when the cages are small and scattered along both sides of a passageway.

The lack of any provision for the purchase of animals has worked serious disadvantage to the collection. Under the most favorable circumstances the mortality in a collection of animals confined under unnatural conditions is very great, and constant additions must be made if its scientific value is to be maintained. The park has for the last year been forced to depend upon gifts, loans, and collections sent from the Yellowstone Park. Gifts have been rare and mostly insignificant. The animals collected at the Yellowstone Park by direction of the honorable the Secretary of the Interior have, while important and valuable, cost more for transportation alone than similar animals would have cost if purchased of dealers and safely delivered at their expense. Various other schemes of collection have been tried, all of which have proved more expensive than purchase would have been. It is hoped that in time, as the National Zoological Park becomes more widely known, the same advantages of cheap purchase will be offered to it as are now made use of by dealers; that is, that the animals brought in by sailors or captured by hunters will be sent to it at low prices. Even now such offers are frequently made, though they are necessarily refused, as the appropriation does not allow any purchases.

Experience has shown that there should be provision made for a resident superintendent. At present the entire park and animals are left at night in charge of watchmen only. If any exigency arises it must wait for morning to bring relief. The isolation of the buildings housing the animals, and the distance of the park from town, make it the more necessary that there should always be at hand, within call, some person of authority to direct in case direction is needed. For this the Holt house may be made available. It is in a part of the park reserved for administrative purposes, and a portion of it now accommodates the office. With a small outlay it could be made a suitable dwelling. The advantages of such an arrangement are too obvious to be recounted, and the effect upon the employés of the constant presence of the superintendent would be very beneficial.

The number of animals at present in the park is 504. Of these 322 are native and 182 foreign. In the appendix to this report tables are given showing the accessions in detail.

ASTRO-PHYSICAL OBSERVATORY.

In my report for 1890–'91 reference was made to the circumstances which led to the establishment of the astro-physical observatory, and in that of last year I gave a brief description of the general object and

scope of such an establishment, touching upon some of the essential features of the work which had been undertaken under my direction.

An explicit description of the specially important investigation which has been continued during the last year, and which is now drawing to a completion, can not so well be given here as in a later portion of the report to which the reader is referred, but the general object of the immediate work is, as has already been stated, the detailed investigation of that great spectral region, still nearly unknown, where yet the greater portion of the solar energy is known to be displayed; or, in other words, of that invisible portion of the solar spectrum which lies beyond the limit of the red.

That the solar spectrum did not cease at the limit of visibility has long been known, and the attention of many distinguished physicists has been directed to the investigation of this invisible part, whose presence is manifest neither to the eye nor to any ordinary process of photography, but which nevertheless comprises more than three-fourths of the energy which the sun sends to us. Were the range of the human eye vastly extended so as to enable us to receive impressions corresponding in character to the kind of energy which is present in this infra-red region we should see in it phenomena of precisely the same character as we now see in the limited spectral region to which we are physiologically limited. It was probably this idea which led Melloni to the use of the term "heat color" to convey to the mind some idea of this similarity between the invisible and the ordinary visible spectrum, and this term expresses by the force of association the characteristics distinguishing one portion of this region from another, characteristics which, although unrecognized by the eye or by any of our senses directly, are yet more striking in their various physical results than the various colors which mark out to the eye the great divisions of the visible spectrum.

The invisible spectrum, then, is marked by narrow bands or lines, which are almost entirely devoid of energy, quite like those which appear in the visible spectrum as black lines and are known as the "Frauenhofer lines." It is to the study of these Frauenhofer lines of the visible spectrum, that we owe nearly all those recent advances which have not only given us definite information as regards the constitution and nature of the heavenly bodies, but have been of immense advantage in the study of meteorological and atmospheric phenomena on the earth. The practical importance of the study of the character of these lines in the invisible spectrum (where their intensity and probably their number is far greater than in the visible) then is evident.

Here, however, all ordinary methods of spectroscopic investigation fail; but long since the writer devised a method which has in the course of the last two years been perfected to such a degree as to enable us to search out the lines in this invisible spectrum and to map them with

a degree of accuracy only inferior to that which can be attained by the eye.

The instrument by which this is accomplished is the bolometer, which, as now constructed, is a minute strip of metal barely $\frac{1}{500}$ of an inch wide, and less than $\frac{1}{5000}$ of an inch thick. Through this frail thread of metal a current of electricity is continually kept flowing. When the spectrum, visible or invisible, is thrown upon it, the thread is warmed and the current decreased by an amount corresponding to the intensity of the effect received, while novel instruments specially mounted and constructed, are in electric connection with the thread and now automatically record every minute change in this current.

With late improvements these instruments are so delicate that a change of temperature of one millionth of a degree is readily detected nd even measured, and it is easy to see that as a consequence of this delicacy the greatest care must be taken in their use. Thus the laboratory must be almost completely darkened, and closed tightly, so as to exclude all drafts and to keep it at as nearly a uniform temperature as possible, while for other reasons it must be kept under constant hygrometric conditions.

The passage of wagons or carriages in the neighboring streets even is liable to cause serious trouble. Hence, the necessity for as complete isolation of the laboratory as possible, and the rigorous exclusion at all times of all whose presence is not indispensable.

In addition to these difficulties there are others of specially trying character due to the nature of the work.

To maintain other necessary conditions, the opening of a door or window for purposes of ventilation is forbidden, even in summer, although the temperature sometimes rises to 100° and even 110°, rendering the work of observing in the small, non-ventilated and darkened room very trying to the health of the observer. Frequent changes in the staff of the Observatory have been necessary for this and other reasons, and the progress of the work has been delayed in consequence. In spite of these and other difficulties, most of which are due to the very temporary and inefficient nature of the small wooden building in which the work is carried on, and its proximity to the traffic-laden streets, the expectations of last year have been largely realized, and a detailed publication of the work accompanied by charts showing several hundred new and before unknown lines, will shortly be issued.

Important as these results are, they are but the beginning of what it may be hoped will be accomplished, with proper facilities.

In view of what has been already accomplished, I hope that Congress will see fit to make provision for the needs of the Astro-physical Observatory in the provision of a suitable site, the money for a small permanent building being already available through the provisions made by friends of the Institution whose contributions for this purpose have already been acknowledged.

NECROLOGY.

RANDALL LEE GIBSON.

Randall Lee Gibson was born at Spring Hill near Versailles, Ky., September 10, 1832; was educated in Lexington, Ky.; in Terre Bonne Parish, La.; at Yale College, and in the law department of the Tulane University of Louisiana. During the civil war he commanded a company, regiment, brigade, and division in the Confederate army. He was a representative in the Forty-fourth, Forty-fifth, Forty-sixth, and Forty-seventh Congress, and was elected to the Senate in 1883, and his second term as Senator would have expired on March 3, 1895.

Senator Gibson was appointed a Regent of the Smithsonian Institution December 19, 1887, and was reappointed March 28, 1889, filling the office till his death, on December 15, 1892. His services as a Regent were warmly recognized in the memorial and resolutions presented at the meeting of the Board on January 25, 1893.

Senator Gibson brought to the performance of his duties as Regent a rare preparation as student, scholar, and statesman. With inherited talents for oratory, and with strong literary tendencies, he was surrounded in youth by all the influences that direct the energies of a man to the public welfare. At Yale College he took a very prominent stand in a group noted for talent and enthusiasm. Foreign travel, the study of law, the life of a planter, a distinguished military career, and long service in the Congress of the United States, filled his capacious mind with a store of a rich and varied experience, and trained him for the highest duties. Life was to him a consecration to public duty, and the performance of that duty his highest felicity. Benevolent, brave, patient, prudent, faithful, his grace and gentleness were the rich drapery of an inflexible will and tenacious purpose.

He came to the Smithsonian Institution as a servant animated by the fullest sense of his responsibilities and self-pledged to a rigid performance of them. His interest in the Institution has been limited only by the conditions of his position. His death, which occurred at Hot Springs, Ark., on December 15, 1892, is a loss to his State and his country, in whose councils he has served for eighteen years.

THOMAS GEORGE HODGKINS.

Thomas George Hodgkins was born in England in 1803, and his early boyhood was spent there. When about 17 years of age, led by a youth's love of adventure, as well as by the desire to aid his family, then in somewhat reduced circumstances, he shipped on one of the East India Company's vessels, and made a voyage to the farther east, where he narrowly escaped death by shipwreck. Consequent upon this misadventure, came confinement in a hospital in Calcutta for some months. During this period of enforced quiet and physical inaction, he formed the resolve that his life, if spared, should henceforth be devoted to advancing the welfare of his fellow men.

After recovery he returned to England, where he married. A few years later he came to the United States, and in 1830 established himself as a manufacturer in New York City. Such success attended his business ventures that in 1859 he withdrew from active pursuits and returned to Europe, where he traveled for some years. His heart, however, led him again to this country, which he had chosen as the home of his early manhood, and which he now made the abiding place of his mature years. In 1873 he bought a country place near the village of Setauket, on Long Island, which he named "Brambletye Farm," and which became his home for the remainder of his life.

Those who had the privilege of a personal acquaintance with Mr. Hodgkins saw in him not only a man of unusual judgment in business affairs, of broad and far-reaching philanthropy, and of deep sincerity in his purpose to benefit his fellow-creatures, but they were struck by the breadth of his views as expressed in connection with subjects generally held to pertain more exclusively to purely scientific research, every domain of which he gladly sought to make contributory to his earnest desire to benefit mankind.

His life was simple and his wants but few, and requiring only a small portion of the products of the home farm for his own use, he pursued his long-established habit of systematic benevolence by giving the remainder to those around him.

Fulfilling also the purpose, formed long years before, to further the good of mankind by all means at his command, he devoted the greater part of his large fortune to various benevolent objects, reserving but a comparatively small sum for his own support.

His sympathy for the helpless and weak led him to contribute largely to the American Society for the Prevention of Cruelty to Children, and to the American Society for the Prevention of Cruelty to Animals. He gave $100,000 to the Royal Institution of Great Britain and $200,000 to the Smithsonian Institution, stipulating that while the latter sum should be included with the original Smithson Foundation, that the income from one-half of it should be devoted to researches and investigations on atmospheric air in connection with the welfare of man.

The death of Mr. Hodgkins occurred at his home in Setauket on the 25th of November, 1892. Those whose duty it is to carry out the plans and to administer the trust laid upon them by the bequest of this man, who so simply and earnestly determined to make the world better by his life, are glad to know that he had the satisfaction of living to see, and to approve the initiatory steps taken in administering the Hodgkins fund of the Smithsonian Institution. A biography of him, in some respects fuller and more personal, will be found in the minutes of the Board of Regents for the present year.

Respectfully submitted,

S. P. LANGLEY,

Secretary of the Smithsonian Institution.

APPENDIX TO SECRETARY'S REPORT.

APPENDIX I.

THE NATIONAL MUSEUM.

The detailed report of the Assistant Secretary in charge, upon the operations of the Museum for the year will be published as Part II of the Report of the Smithsonian Institution. I shall here speak of only the more important matters.

Additions to the collections.—The additions to all departments of the Museum during the year number 82,148 specimens. These were for the most part miscellaneous in character, and, while valuable in themselves, did not tend to so large an extent to supply gaps in the various series as would be the case were larger funds available for purchases. Important collections made by the U. S. Geological Survey, U. S. Fish Commission, and several other bureaus of the Government, in connection with their regular work, have been transmitted to the Museum. With the care of such collections the Museum is charged by act of Congress.

A table showing the number of specimens now in each department of the Museum and for each year since 1882 accompanies the report of the Assistant Secretary which has been already referred to.

The scientific staff.—The number of scientific departments in the Museum remains the same as last year, and few changes in the personnel have been made. Mr. Frederick W. True, curator of mammals, has been designated "Curator-in-charge" and acts as the executive officer of the Museum, in the absence of the Assistant Secretary.

The proportion of honorary curators remains the same as last year. About five-sevenths of the departments are presided over by unpaid officers who are officially attached to other departments and bureaus of the Government, especially the U. S. Geological Survey and the U. S. Fish Commission. This arrangement is in the interest of economy, but it is not conducive to the general welfare of the Museum that the proportion should be so large as at present, since the necessity of devoting most of their time to other matters makes it impossible for the honorary curators to advance the work of their departments as they could if they were attached to the Museum alone.

Distribution of specimens.—It has for many years been customary to distribute to educational establishments, as far as practicable, the duplicate material separated from the Museum collections. This has been possible hitherto, as a part of the systematic operations of the Museum, only in the case of fishes, marine invertebrates, rocks, minerals, and casts of prehistoric implements, although special collections have occasionally been prepared to meet special needs. A large number of sets of rocks and minerals have been sent out during the year. During the two decades from 1871 to 1890 about 278,000 specimens in all were distributed. The duplicates in other departments of the Museum are being arranged in sets for distribution as fast as the facilities at the disposal of the curators permit.

During the year ending June 30, 1893, the number of specimens sent out in exchange or distributed to educational institutions was 13,581.

Visitors.—The total number of visitors to the Smithsonian building during the year was 174,188, and to the Museum building 319,930, giving a total of 494,188 persons who

visited the two buildings. This total shows an increase of 109,476 over the previous year.

Publications.—The Report of the National Museum for 1890 (Part II of the Smithsonian Report) has been published, and that for 1891 will shortly be issued. The report for 1892 is in the hands of the Public Printer.

Volume XIV of the Proceedings of the Museum has been issued in bound form, and all the separate papers composing Volume XV have been received and distributed. The manuscript of a number of papers belonging to Volume XVI has also been sent to the Public Printer, and several of these were issued in pamphlet form before the close of the fiscal year.

Part F, of Bulletin No. 39, "Directions for collecting and preserving insects," by C. V. Riley, and Part G, of the same Bulletin, "Instructions for collecting mollusks and other useful hints for the conchologist," by William H. Dall, and also Bulletin 40, "The Published Writings of George Newbold Lawrence, 1844–1891," by L.S. Foster, have been published. Bulletin 41, "The Published Writings of Dr. Charles Girard," by G. Brown Goode, and Bulletin 42, "A preliminary descriptive catalogue of the systematic collections in economic geology and metallurgy in the U. S. National Museum," by Frederic P. Dewey, were issued during the preceding year.

The manuscript for Bulletin 43, "A Monograph of the Bats of North America," by Harrison Allen, M. D., Bulletin 44, "Catalogue of the Lepidopterous Superfamily Noctuidæ found in Boreal America," by John B. Smith, Bulletin 45, "The Myriapoda of North America," by Charles Harvey Bollman, and Bulletin 46, "Monograph of the North American Proctotrypidæ," by William H. Ashmead, has been sent to the Public Printer, the illustrations have been engraved, and the text put in type. Special Bulletin No. 1, "Life Histories of North American Birds," by Capt. Charles E. Bendire, honorary curator of birds' eggs in the Museum, has been issued. This is the first quarto volume published by the Museum. Special Bulletin No. 2, "Oceanic Ichthyology," a monograph of the deep sea and pelagic fishes of the world, by G. Brown Goode and Tarleton H. Bean, is in the hands of the Public Printer, and it is expected that the volume will be ready for distribution early in the next year.

The demand for the Museum publications has increased to such an extent that many worthy applications are daily refused. An increase in the allotment for printing can not be too strongly urged, in order that the Museum may be enabled to place a full series of its publications in representative libraries in different parts of each State. If a wider distribution of publications of the Museum were provided for, the Museum would undoubtedly receive in exchange the valuable publications of many scientific institutions which are at present only meagerly represented in its library.

The World's Columbian Exposition.—On April 25, 1890, an act "to provide for celebrating the four hundredth anniversary of the discovery of America by Christopher Columbus by holding an international exhibition of arts, industries, manufactures, and the product of the soil, mine, and sea in the city of Chicago, in the State of Illinois," was approved by the President of the United States. This act authorized the participation of the Executive Departments, the Smithsonian Institution and National Museum, and the U. S. Fish Commission in the Exposition. A Government Board of Control was organized, consisting of representatives of each of these Departments. They were appointed by the President of the United States, and under their control was placed the preparation, installation, and administration of the Government exhibit. Upon my recommendation, Dr. G. Brown Goode, Assistant Secretary of the Smithsonian Institution in charge of the National Museum, was appointed Representative of the Smithsonian Institution and National Museum.

As soon as the character and scope of the exhibit had been decided upon, agents were at once instructed to proceed to various localities, with a view to collecting material necessary for illustrating the condition of the continent at the time of its

discovery by Columbus, and for representing the animal life and the natural resources of the country. The work of mounting and arranging the specimens was immediately begun, and continued until the beginning of the present calendar year.

In February, the first shipments to Chicago were made. The entire exhibit filled twenty-nine cars. On the opening day, May 1, the exhibits were all in place and were formally opened to the public.

In the act authorizing the Exposition special provision was made for the construction of a separate building for the exhibits of the United States Government, at a cost of $400,000. About 22,000 square feet of floor space were assigned to the Smithsonian Institution and National Museum at the south center of the building.

Before closing these statements I feel it my duty again to allude to the overcrowded condition of the halls of the present Museum building. This has been temporarily alleviated to some extent by the transmission of a large number of specimens from several departments of the Museum to the World's Columbian Exposition, but at the close of the Exposition these objects will be returned. Some provision must also be made for the objects which were acquired especially for the Exposition, as well as for material which will doubtless be presented to the United States by foreign governments and private exhibitors.

I have already called attention to the large number of specimens, now in the storerooms, which have never yet been provided for, and which are in danger of deteriorating, owing to the impossibility of properly caring for them. I am aware that the burden of these remarks has become an annual repetition, but I feel it my duty to continue to make these representations until Congress, upon whom the responsibility falls, shall erect an additional Museum building, or at least fire-proof storage-sheds.

I must again call attention to the need of larger appropriations for the current work. The number of visitors and the demands of the public are constantly increasing, and more money is necessary in order to carry on legitimate work in a business-like and effective manner. The clerical employés are paid less than in the Executive Departments, and many of them leave after a short period of service, to the serious detriment of the Museum, which is compelled to train new clerks.

In the matter of heating and lighting, to which I called special attention in my last report, I trust that the full amount asked for, including the cost of new heating apparatus, which I have estimated at $4,000, will be allowed by Congress. I may add that much sickness has occurred during previous winters owing to the impossibility of keeping all the offices in the building properly heated with the small amount of coal which could be purchased.

Appendix II.

REPORT OF THE DIRECTOR OF THE BUREAU OF ETHNOLOGY FOR THE YEAR ENDING JUNE 30, 1893.

Sir: I have the honor to submit the following report on the work of the Bureau under my charge during the fiscal year ending June 30, 1893. In recent years the researches of the Bureau have been largely topical and carried forward along lines representing the chief natural divisions of ethnologic science. The report is arranged by these subjects of investigation.

PICTOGRAPHY AND SIGN LANGUAGE.

Researches concerning the pictography and sign language of the native American tribes were continued by Col. Garrick Mallery, who spent a part of the year in the field in northern New England and contiguous territory in special work among the survivors of the Abnaki, Micmac, and other Algonquian tribes. The work resulted in substantial additions to knowledge of the picture writing and gesture speech among these people. During the greater part of the year Col. Mallery was occupied in the office first in preparing and afterward in revising and correcting the proof sheets of his extended report entitled "Picture writing of the American Indians," which forms the greater part of the tenth annual report of the Bureau. This elaborate treatise is a practically exhaustive monograph on the subject to which it relates. The plates and text illustrations, which together comprise nearly fourteen hundred figures, were collected with care and represent the aboriginal picture writing of all portions of the country with fidelity, while the significance and relations of the glyphs are discussed in detail in the text.

During the later portion of the year, in intervals of the work of proof revising, Col. Mallery continued the collection and arrangement of material relating to the sign language of the American aborigines. A preliminary treatise on this subject was published in one of the early reports of the Bureau; but since that time, partly through the stimulus to study of the habits and customs of our native tribes afforded by that publication, a large amount of additional material has been obtained. It is the purpose to collate and discuss this material in a final monograph, which will be, it is believed, even more comprehensive than that on pictography, and Col. Mallery has made satisfactory progress in this work.

Dr. W. J. Hoffman, who has for some years been associated with the work on pictography and sign language, was occupied during the greater part of the year in collateral researches relating to the ceremonies of a secret society (the "Grand Medicine Society") of the Menomoni Indians of Wisconsin. Beginning with the study of the pictographs and gestures of these Indians he gradually extended his investigations to other characteristics of the tribe, and for three years in succession attended the initiation of candidates into their most important secret society, and was thus enabled to obtain the archaic linguistic forms used only in the language employed in the esoteric ritual. The data collected were subsequently collated with a view to publication. Some attention was also given to linguistic matter, including gesture speech, collected among the Absaroka Indians in Montana and the Leech lake band of Ojibwa Indians in Minnesota.

ARCHEOLOGY.

Archeologic researches were actively continued by Prof. W. H. Holmes, with several collaborators and assistants, in different eastern States and in the interior. The work in eastern United States has been notably rich in results of scientific value. Prof. Holmes examined in detail the novaculite quarries of Arkansas, the pipestone quarries of Minnesota, and the ancient copper mines of Isle Royale, Mich. He also made important studies at various points in the valleys of Potomac, Genesee, and Ohio rivers, and his surveys and examinations in the Delaware valley, particularly about Trenton, were especially extended. At the last-named locality advantage was taken of the excavation of a broad and deep trench parallel with the river front at Trenton to study carefully the late glacial gravels commonly supposed to yield human relics. For a period of six weeks the excellent exposures made in this trench, 25 to 35 feet deep, were constantly watched by Prof. Holmes and Mr. William Dinwiddie, without, however, the finding of a single artificial object in the previously undisturbed gravels. This negative result is believed to be of great importance to American archeology. Special examinations, frequently requiring excavations, were made of the ancient soapstone quarries of the District of Columbia and in Virginia, Mr. Dinwiddie and Mr. Gerard Fowke aiding in the work; and toward the close of the year Mr. De Lancey W. Gill, of the U. S. Geological Survey, was detailed to make an examination of the ancient mica mines of North Carolina. Valuable collections of material representing aboriginal arts and industries grew out of this work.

In December Prof. Holmes was placed in charge of the exhibit of the Bureau of Ethnology for the World's Columbian Exposition at Chicago, and several months were occupied mainly in preparing, classifying, labeling, and arranging the exhibit, which includes (1) a series of collections illustrating aboriginal quarrying, mining, and implement-making industries; (2) various collections of ethnologic material made chiefly by collaborators of the Bureau; and (3) a series of life-size figures illustrating the domestic life, arts, and industries of the aborigines. It is a pleasure to observe that this exhibit attracted great attention among visitors to the Fair. Messrs. H. W. Henshaw, James Mooney, F. H. Cushing, and Gerard Fowke aided in the preparation of this exhibit.

At intervals throughout the year Prof. Holmes continued researches concerning the development of the shaping arts. Hitherto, American archeologists have in general been content to accept the classification of prehistoric peoples into culture stages based on the products of art work in stone, the classification being derived from European studies. During the last decade different archeologists have devoted much attention to the development of pristine culture as indicated by the artificial stone implements, weapons, and other objects found in many parts of this country, and have come to question the applicability of the European classification. While the investigation can not be regarded as complete, it is worthy of note that a large body of data has been brought together which seem to afford a basis for an indigenous classification of primitive American art products. This classification will, it is believed, eventually give character to that branch of American archeology which deals with art in stone.

Mr. Cosmos Mindeleff continued his study of the Pueblo relics and prepared an elaborate treatise on the subject for the press. This work, under the title "Aboriginal Remains in the Valley of the Rio Verde," is now completed and forms part of the thirteenth annual report. It illustrates in detail the architecture and various industrial arts recorded in the ruined cities of pre-Columbian tribes in the Southwest.

In addition to the surveys and researches already noted, Mr. Gerard Fowke was employed for several months in archeologic explorations in Ohio. He was able to obtain much valuable material.

INDIAN MOUNDS.

The researches concerning the ancient Indian mounds distributed over many portions of the country, particularly the Mississippi Valley, have been continued by Dr. Cyrus Thomas. The chief work during the year has been the preparation of matter for publication and the revision of proofs of text and illustrations. The principal results of Dr. Thomas's researches are incorporated in a monograph of over 700 pages in the eleventh annual report. Several minor papers relating to different classes of articles collected from mounds also are in various stages of preparation, two being ready for publication.

In addition to his special work on the Indian mounds, Dr. Thomas was able to devote some time to the study of certain Mexican codices of exceptional archeologic interest. Considerable progress has been made in analyzing the characters of the Maya codices, and it is believed that these highly significant inscriptions may ultimately be deciphered by means of the methods devised and pursued by him.

No field work was conducted in this branch of the Bureau during the year.

SOCIOLOGY.

The work on sociology of the American Indians was continued by Mr. H. W. Henshaw. The earlier part of the year was spent in collecting sociologic and linguistic materials among the Indians of Butte, Mendocino, and San Diego counties, California. Early in 1893 Mr. Henshaw was unfortunately compelled by ill health to ask for indefinite leave of absence.

Mr. James Mooney spent the greater part of the year in the field collecting information concerning the Sioux ghost dance, and concerning the habits, customs, and social relations of the Kiowa and other tribes, visiting the Sioux Indians at Pine Ridge, S. Dak., the Shoshoni and northern Arapaho in Wyoming, and the Cheyenne, southern Arapahos, Kiowa, Comanche, and associated tribes in Oklahoma. In addition to valuable literary material, he made important collections of objects representing aboriginal life, including a series of Kiowa shield models with illustrative pictography affording data for a study of primitive heraldry, and three important calendars.

In December Mr. Mooney was commissioned to make collections among the Navajos and Moquis of New Mexico and Arizona for exhibition at the World's Fair. This work resulted in a remarkable collection of unique material from two of our most interesting native tribes, including the products of industrial arts, costumery, etc., as well as the photographs and materials needed for preparing and exhibiting a series of groups of life-sized figures illustrating domestic life, industries, and ceremonies. In addition an unprecedentedly extensive collection of Indian food products was obtained for the National Museum.

LINGUISTICS.

Linguistic researches were continued by Rev. J. Owen Dorsey, Dr. Albert S. Gatschet, and Mr. J. N. B. Hewitt. Mr. Dorsey continued his investigations in connection with the report on Indian synonymy, making a thorough study of the Catawba tribes and their habitats. He also resumed work on the Biloxi language, at first using the material collected during the previous year, arranging the Biloxi verbs in fourteen conjugations, making a list of Biloxi onomatopes, and compiling a Biloxi-English vocabulary of about two thousand entries together with a catalogue of Biloxi roots. For the purpose of carrying this investigation to completion he visited Lecompte, La., during the winter and spent two months with the survivors of this interesting tribe. In addition he practically finished the work of editing the manuscript of Riggs, "Dakota Grammar, Texts and Ethnography," which constitutes Volume IX of the series of Contributions to North American Ethnology. Proofs of this work, which is about to leave the press, were revised during the latter portion of the year.

The earlier part of the year was spent by Dr. Gatschet in the study of the Wichita

language at the Educational Home for Indian boys in Philadelphia. Special attention was given to the Wichita verb, which, like the verb of all the Caddoan languages, is highly complex in its inflections and in the permutability of its consonants. From October 1 up to the end of April Mr. Gatschet was occupied in the study of the Peoria, Shawnee (or Shawano), Arapaho, and Cheyenne languages in Indian Territory. Eight weeks were devoted to the Peoria language, during which period over three thousand terms and a corresponding number of phrases and sentences were collected and revised. This study is deemed of exceptional interest, since no texts of the Peoria language are known to have appeared in print.

The Shawnee was the language next taken up. Assisted in the field by good interpreters, Dr. Gatschet obtained copies and reliable material in texts of the phraseology and terms of the Shawnee language, a number of verbal and nominal paradigms, and a choice selection of instances showing the multiplicity of duplication.

Subsequently he took up the Arapaho and Cheyenne languages. Both are nasalizing and are spoken in several dialects differing but little from each other. Ample collections were made of lexical and phraseological material, with texts and some poetic specimens. The ethnographic study of these genuine prairie Indians is highly interesting, since they have had but a few years of intercourse with the white man and his civilizing, as well as corrupting, influences.

Mr. Hewitt continued his work on the Iroquoian languages, with which he is thoroughly familiar. He was able to ascertain and formulate the principles or canons governing the number, kind, and position of notional stems in symphrases, or word-sentences. Six rules are formulated which establish and govern the morphologic ground plan of words and word-sentences. These are as follows:

First. The simple or the compound stem of a notional word of a word-sentence may not be employed as an element of discourse without a prefixed simple or complex personal pronoun, or sign or flexion denotive of gender, the prefixion of the latter taking place with nouns only.

Second. Only two notional stems may be combined in the same word-sentence, and they must belong respectively to different parts of speech.

Third. An adjective-stem may not combine with a verb-stem, but it may unite with the formative thâ', to make or cause, or with the inchoative ç.

Fourth. The stem of a verb or adjective may combine with the stem of a noun, and such stem of a verb or adjective must be placed after and never before the noun-stem.

Fifth. A qualificative or other word or element must not be interposed between the two combined stems of compound notional words, nor between the simple or compound notional stem and its simple or complex pronominal prefix.

Sixth. Derivative and formative change may be effected only by the prefixion or suffixion of suitable flexions to the morphologies fixed by the foregoing rules or canons.

Mr. Hewitt also continued his general study of the Iroquoian languages described in previous reports, and collected additional material relating to the manners, customs, and history of the Iroquis Indians, chiefly by translation and abstraction from the Jesuit relations and accounts of the early French explorers. He also continued work on the Tuskarora-English dictionary and grammar.

MYTHOLOGY.

The researches in mythology, by Mr. Frank Hamilton Cushing and Mrs. Matilda Coxe Stevenson, were continued throughout the year. Mr. Cushing was occupied chiefly in arranging and collating material previously collected, with a view to publication. An important result of his work is the demonstration of the fact that the mythic concepts, which form so large a part of the intellectual life of primitive peoples are greatly modified by the bodily organs and functions exercised in their expression. In some cases this relation between organ or function on the one hand and concept on the other is so intimate as to justify the ascription of the modern con-

cept to dual causes, of which the first is intellectual, while the hardly less essential second cause is physiologic; *e. g.*, it may be shown conclusively that the decimal system forming the basis of the arithmetic of certain southwestern tribes is essentially indigenous and has grown up through successive generations from counting on the fingers in certain definite ways. This relation between concepts and physiologic structure is especially significant in its bearing on the development of primitive mythology.

Mrs. Stevenson was occupied during a part of the year in revising for the press her report entitled "The Sia," which forms the leading paper of the twelfth annual report of the Bureau, now in the hands of the printer. She was also engaged for several months in the preparation of a memoir on the secret societies and ceremonials of the Zuñi Indians. Mrs. Stevenson's researches on these southwestern tribes have not only resulted in important contributions to knowledge of the primitive beliefs by which the daily life of these peoples was governed, but have also thrown light on the migrations and ethnic relations of their ancestors. The monograph on this subject, which is illustrated by numerous graphic representations, is approaching completion.

BIBLIOGRAPHY.

The work on bibliography of native American languages was continued by Mr. James C. Pilling. Two numbers of the series of bibliographies were issued as bulletins of the Bureau during the year, another was sent to press, and a fourth was nearly completed in manuscript. The later proofs of the sixth of the series, which relates to the Athapascan languages, were revised early in the year. The work was subsequently issued as a bulletin of 138 pages, embracing 544 titular entries with 4 facsimile reproductions. Although the publication was not distributed until spring of the present calendar year, it has already been favorably noticed in scientific journals in this and other countries; and the critical reviews show that the students of our native languages place this work by Mr. Pilling on the same high plane accorded the previous volumes of the series.

The bibliography of the Chinookan languages (including the Chinook jargon) was sent to press in October and proof revision was finished in April. In the compilation of this bibliography much attention was given to the origin and growth of the Chinook jargon, or "trade language," of the northwestern coast, which has come to be an international dialect, affording the established means of communication between the whites and the several native tribes occupying the region between the State of Washington and Alaska, whose languages are many and diverse. While this bibliography (the seventh of the series) comprises but 94 pages and includes only 270 titular entries, it is believed that it will prove no less valuable to linguistic students than the earlier numbers, since it is substantially a record of a dead language, there being but one man now living who fully understands the tongue on which the linguistic relations of the family rest. The edition of this bulletin was delivered by the Public Printer in May.

The manuscript of the bibliography of the Salishan languages was sent to press in March, and proof revision is in progress. This work exceeds in volume the Chinookan bibliography, and, like that, deals with the records of one of the highly interesting group of native tongues of our Pacific region, which, though doomed to early extinction, are among the most important sources of information concerning the development of language.

Toward the close of the year Mr. Pilling was occupied in preparing for the press the bibliography of the Wakashan languages, the ninth number of the series, which is now well advanced.

The value of the several bibliographies has been greatly enhanced, and their preparation has been materially facilitated through the cooperation of linguistic students in different parts of the country. Special acknowledgments are due Mr. Horatio Hale, the well-known philologist, and Mr. J. K. Gill, author of a dictionary

of the Chinook jargon, for aid in the preparation of Chinookan bibliography; and Mr. Pilling acknowledges equal obligations to the Rev. Myron Eells and Dr. Franz Boas for information concerning the Chinookan and Salishan languages.

SYNONYMY OF INDIAN TRIBES.

The preparation of this work, which has engaged the attention of nearly all the collaborators of the Bureau at various times, is well advanced. During the year Messrs H. W. Henshaw, F. Webb Hodge, James Mooney, and J. Owen Dorsey have contributed to the work. The portions of the synonymy relating to the tribes of the following stocks are ready for publication:

Attacapan, Beothukan, Kalapooian, Karankawan, Kusan, Lutuamian, Muskhogean, Natchesan, Skittagetan, Timuquanan, Tonikan, Uchean, Yakonan, and Yuman.

In addition, the Algonquian and Iroquoian families—two of the largest and most important—require comparatively little elaboration by Mr. Mooney (to whom these stocks were originally assigned) to make them ready for press.

When his other duties permitted Mr. Hodge devoted attention to the elaboration of material pertaining to the Piman family, as well as that of the Pueblo stocks (Zuñian, Keresan, Tañoan, and the Tusayan division of the Shoshonean). Very little work is now required to finally complete for publication the material relating to these tribes. In addition, Mr. Hodge introduced into the descriptions formerly made of some twenty stocks (principally in California) a large body of new material made known by recent investigators.

PSYCHOLOGY.

Within recent years it has come to be recognized by many ethnologists that the mythic concepts, and through these the social institutions, of primitive peoples are dependent on a limited number of factors, including (1) individual and tribal environment and (2) individual and collective modes and habits of thought. Now the first of these factors has received the attention of nearly all investigators, while the second has received much less consideration and is frequently ignored. Accordingly, it has been thought desirable to undertake the investigation of intellectual method for the purpose of developing the principles of psychology, and thus affording a more definite basis for the researches in mythology and sociology. To this subject the Director has devoted a considerable part of the year, and a tentative system of psychology which will, it is believed, prove a useful guide for further researches has been formulated.

EXPLORATION.

The Director spent several weeks in ethnologic exploration in the Northern Pacific slope. The territory lying between the Sierra Nevada Mountains and the Pacific is of exceptional value to ethnologists by reason of the remarkable number of independent linguistic stocks crowded into a relatively small area; three-fourths of the distinct groups of peoples in this country, and fully half of all known on the Western Hemisphere, are found in this locality. The northern part of the tract has never been explored by students; and in the hope of discovering additional stocks among the remaining tribes, and in the hope of gaining additional knowledge concerning the origin of this remarkable diversity of languages, an exploratory trip was planned. The results of the observations are incorporated in reports now in course of preparation for the press. Mr. Henshaw, in southern California, and Mr. Mooney, in the northern Rocky Mountain region, also penetrated areas and encountered Indians not previously seen by scientific students.

MISCELLANEOUS WORK.

As incidentally noted in preceeding paragraphs, much time and thought have been given to the installation of an ethnologic exhibit in the World's Columbian Exposition at Chicago. This exhibit occupies the southern portion of the Govern-

ment building. It comprises a large amount of material of popular as well as scientific interest, derived from various portions of the country, a considerable part of this material having been collected or prepared especially for the Exposition. Most of the collaborators of the Bureau have contributed directly or indirectly to this exhibit.

The work of the modeling department has been continued. The chief work has lain in the restoration and repair of models previously constructed and exhibited at the expositions in New Orleans and Madrid. A number of new models and several replicas of models already constructed have, however, been executed, chiefly for use in the Columbian Exposition.

During the year an exceptional number of applications for definite information concerning our native tribes have been received from the publishers of encyclopedias, dictionaries, physical geographies, and other standard works, and in view of the educational value of these publications and the manifest public advantage to be gained from the diffusion of the results of the latest scientific researches, it has been deemed important to respond to such applications as fully as possible. Much information has been disseminated in this way during the year, and several encyclopedia articles have been prepared by the director and different collaborators of the Bureau.

ILLUSTRATIONS.

The work connected with the illustration of reports has been continued under the supervision of Mr. DeLancey W. Gill, chief of the division of illustrations of the Geological Survey, the actual labor of executing drawings being performed in large part by Miss Mary Irvin Wright and Miss Mary M. Mitchell. Most of the work done by the former artist is highly elaborate, comprising drawings of pueblo life and ceremonials and representations of scenes in the ceremonials of the Sioux ghost dance. The chief work of the latter has been the preparation of drawings of Indian implements, principally objects of stone. Two hundred and fifty-seven original drawings designed for reproduction by various processes were executed during the year.

One thousand three hundred and forty-four engraved proofs have been received from the Public Printer during the fiscal year and have been examined, revised or approved, and returned. The printed editions of all chromolithographs used in the publications of the Bureau have also been examined and the imperfect sheets rejected.

The photographic work of the Bureau has been ably directed, as in previous years, by Mr. J. K. Hillers. The following statement includes the work done in the photographic laboratory during the year:

Size.	Negatives.	Prints.
28 by 34 inches	42	137
22 by 28 inches	5	10
20 by 24 inches	26	83
14 by 17 inches	65	309
11 by 14 inches	42	85
8 by 10 inches	26	172
5 by 8 inches		629
4 by 5 inches		1,153

I have the honor to be, yours, with respect,

J. W. POWELL,
Director.

MR. S. P. LANGLEY,
Secretary of the Smithsonian Institution

Appendix III.

REPORT OF THE CURATOR OF EXCHANGES FOR THE YEAR ENDING JUNE 30, 1893.

Sir: I have the honor to present the following brief report, chiefly statistical, of the operations of the Bureau of International Exchanges for the fiscal year ending June 30, 1893:

TABULAR STATEMENT OF THE WORK OF THE BUREAU.

The work of the bureau for the year is succinctly given in the annexed table, prepared in a form adopted in preceding reports:

Transactions of the Bureau of International Exchanges during the fiscal year 1892–'93.

Date.	Number of packages received.	Weight of packages received.	Ledger accounts. Foreign societies.	Domestic societies.	Foreign individuals.	Domestic individuals.	Domestic packages sent.	Invoices written.	Cases shipped abroad.	Letters received.	Letters sent.
1892.											
July	7,469	19,228	......	......	......	......	....	....	......	162	147
August	13,635	15,028	......	......	......	......	....	....	......	216	299
September	14,592	14,725	......	......	......	......	....	....	......	157	173
October	5,905	17,342	......	......	......	......	....	....	......	153	146
November	5,508	18,599	......	......	......	......	....	....	......	150	126
December	11,994	16,449	......	......	......	......	....	....	......	139	288
1893.											
January	5,687	12,883	......	......	......	......	....	....	......	165	147
February	6,038	20,305	......	......	......	......	....	....	......	145	170
March	7,379	22,894	......	......	......	......	....	....	......	187	195
April	5,344	12,023	......	......	......	......	....	....	......	166	158
May	11,741	20,328	......	......	......	......	....	....	......	202	243
June	5,771	11,124	......	......	......	......	....	....	......	173	227
Total	101,063	200,928	6,896	2,414	8,554	5,010	29,454	19,996	878	2,013	2,259
Increase over 1891–'92	4,036	*—25,589	692	370	644	486	3,854	*—3,140	*—137	*—310	*—493

* Decrease.

For comparison with previous years I add a tabular statement from 1886 to 1893, inclusive, by which the growth of the service is made apparent:

	1886–'87.	1887–'88.	1888–'89.	1889–'90.	1890–'91.	1891–'92.	1892–'93.
Number of packages received	61,940	75,107	75,966	82,572	90,666	97,027	101,063
Weight of packages received	141,263	149,630	179,928	202,657	237,612	226,517	200,928
Ledger accounts:							
Foreign societies	7,396	4,194	4,466	5,131	5,981	6,204	6,896
Foreign individuals		4,153	4,699	6,340	7,072	7,910	8,554
Domestic societies	2,165	1,070	1,355	1,431	1,588	2,044	2,414
Domestic individuals		1,556	2,610	3,100	4,207	4,524	5,010
Domestic packages sent	10,294	12,301	17,218	13,216	29,047	26,000	29,454
Invoices written	15,288	13,525	14,095	16,948	21,923	23,136	19,996
Cases shipped abroad	692	663	693	873	962	1,015	878
Letters received	1,131	1,062	1,214	1,509	2,207	2,323	2,013
Letters written	1,217	1,804	2,050	1,625	2,417	2,752	2,259

EXPENSES.

The expense of the Exchange Bureau are met in part by direct appropriation by Congress and in part by appropriations made to Government Departments or Bureaus, either in their contingent funds or in specific terms for repayment to the Smithsonian Institution of a portion of the cost of transportation. In 1878 the Board of Regents established a charge of 5 cents per pound weight for the publications sent out or received by the various Government bureaus, this charge being necessary to prevent an undue tax upon the resources of the Institution, as the appropriations made by Congress have never been sufficient to meet the entire cost of the service. For similar reasons it has been found necessary to make a charge of the same amount to State institutions, and from these a further small sum has been received.

The appropriation made by Congress for the fiscal year 1892–'93 was in the following terms: "For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employés, twelve thousand dollars," which amount was supplemented by a deficiency appropriation of $5,000.

The receipts and disbursements by the accounting officer of the Smithsonian Institution on account of international exchanges, under date of July 1, 1893, covering the fiscal year immediately preceding, were as follows:

RECEIPTS.

Direct appropriations by Congress	$17,000.00
Repayments to the Smithsonian Institution from United States Government Departments	1,396.61
State institutions	63.85
Repayment of freight advanced for New South Wales government board for international exchanges	23.50
Total	18,483.99

EXPENSES.

For—	From specific Congressional appropriations.	From other sources.
Salaries and compensations	$13,872.52	
Freight	1,805.01	
Packing boxes	441.40	
Printing	217.85	
Postage	150.00	
Stationery	512.98	
	16,999.76	$1,518.49
Total		18,518.25

The foregoing table shows that the entire amount received from Government bureaus and other sources was $1,483.99, making the sum practically available for the specific purpose of exchanges $18,483.99, while the expenses have amounted to $18,518.25, the deficiency of $34.26 being made up from the Smithsonian fund.

For the year 1892–'93 an estimate for the entire expense of the service of $23,000 was submitted, this sum being intended to include in a single appropriation various

small items in different appropriation bills, and also an item of $2,000 to cover the expense of an immediate exchange of parliamentary documents with the countries entering into the treaty of Brussels in 1886. To this latter treaty for the immediate exchange of the Congressional Record no effect has yet been given by reason of lack of funds. The amount originally appropriated for the service of the year 1892–'93 was $12,000, as stated above, and this was subsequently increased by a deficiency appropriation of $5,000 upon urgent representation of the need of this further amount to carry the work through the year.

CORRESPONDENTS.

The new list of correspondents begun upon small ledger cards, January 1, 1892, has proved of great convenience, and it is only by introducing labor-saving devices in the arrangements for handling the records that it has been at all possible to meet the growth of the service with the smaller clerical force.

The number of new ledger cards on July 1, 1892, was 9,808, and on June 30, 1893, 16,340, classified as follows:

	New list, since January 1, 1892.		Entire list.	
	Foreign.	Domestic.	Foreign.	Domestic.
Societies and institutions	6,670	1,775	6,896	2,414
Individuals	5,308	2,587	8,554	5,010
Total	11,978	4,362	15,450	7,424

INTERNATIONAL EXCHANGE OF OFFICIAL DOCUMENTS.

Under the treaty of Brussels of 1886, the text of which was given in full in the report of the curator of exchanges for 1887–'88, the exchange of the official publications of theUnited States Government with other countries has been continued by the Institution, and it now forms a very large proportion of the bureau's work.

The entire number of publications sent abroad during the year under the provision of the act of Congress of March 2, 1867, and of the treaty above referred to was 31,850, and there have been received in return 5,196 packages. The United States Government Departments have forwarded to their correspondents abroad 16,074 packages, and have received in return 12,922 packages. The total number of exchanges for Government libraries has therefore been 18,118 packages received and 47,924 packages sent abroad, a total of 66,012 packages, or about 65 per cent of the entire number handled.

The very inadequate return for the great number of documents sent out is in part undoubtedly due to the fact that no other country publishes on such a lavish scale as our own. Direct solicitation made by a special representative to the governments with which we are in correspondence would also probably result in a considerable increase to the Library of Congress.

The exchange on account of Government bureaus is shown in detail in the following table:

Statement of Government exchanges during the year 1892–'93.

Name of bureau.	Packages— Received for.	Packages— Sent by.	Name of bureau.	Packages— Received for.	Packages— Sent by.
Smithsonian Institution	11,136	3,616	U. S. General Land Office	4	......
Astro-physical Observatory	7	1	U. S. Geological Survey	406	949
Bureau of Ethnology	107	916	U. S. Hydrographic Office	74	....
Bureau of International Exchanges	8	....	U. S. Indian Affairs Office	3	....
National Zoological Park	1	....	U. S. Interior Department	25	295
U. S. Agricultural Department	130	19	U. S. Interstate Commerce Commission	1	....
U. S. Army Medical Museum	3	....	U. S. Light-House Board	2	1
U. S. Botanic Garden	3	....	U. S. Marine-Hospital Service	6	....
U. S. Bureau of Education	63	....	U. S. Mint	1	....
U. S. Bureau of Navigation	2	....	U. S. National Academy	64	989
U. S. Bureau of Ordnance, Navy Department	1	....	U. S. National Board of Health	1	....
U. S. Bureau of Ordnance, War Department	4	....	U. S. National Museum	161	6,103
U. S. Bureau of Statistics, Treasury Department	25	....	U. S. Nautical Almanac Office	17	141
U. S. Census Office	9	6	U. S. Naval Observatory	106	1,200
U. S. Coast and Geodetic Survey	61	19	U. S. Navy Department	1	....
U. S. Commissioner of Weights and Measures	1	....	U. S. Patent Office	28	573
U. S. Comptroller of the Currency	2	....	U. S. Public Printer	....	31,850
U. S. Congressional Library	5,196	....	U. S. Senate	1	....
U. S. Department of Justice	1	....	U. S. Signal Service	39	....
U. S. Department of Labor	18	3	U. S. State Department	14	....
U. S. Engineer Office	34	98	U. S. Surgeon-General's Office (Army)	170	554
U. S. Entomological Commission	7	....	U. S. Surgeon-General's Office (Navy)	9	....
U. S. Fish Commission	70	246	U. S. Treasury Department	7	....
			U. S. War Department	14	219
			U. S. Weather Bureau	65	126
			Total	18,116	47,924

EFFICIENCY OF THE SERVICE.

I beg to call attention to the unsatisfactory state of the exchange relations with several countries, a condition of affairs which can perhaps in some instances be remedied by proper representations through diplomatic channels. The transmission of exchanges to Greece has been entirely suspended, a letter having been received from the librarian of the United National and University Libraries, formerly acting as the medium for distributing publications, requesting that with the exception of their own exchanges no further boxes be forwarded, on account of the expense attending the distribution of the packages. Correspondence has been opened with a view to establishing a new exchange relation, but so far without success. All transmissions to Brazil and Chile were for a time suspended, owing to the unsettled condition of these countries. With Mexico our exchange relations are also extremely unsatisfactory. Correspondents in Nicaragua meet with what would seem to be unreasonable delay in receiving packages addressed to them, and I regret to state that the Government authorities at Calcutta have declined to receive and dispatch packages addressed to other than Government officials. On the other hand, very efficient international exchange bureaus are now under Government auspices in New South Wales and Uruguay.

Referring to clerical details of the office work, it seems desirable to keep before

the minds of Smithsonian correspondents the system of accounting for the material, often of considerable value, that passes through the exchange office.

Under the name of each individual or society sending or receiving a package through the exchange bureau, an account of all such packages is kept, with the date of transmission and of acknowledgment. It was found possible to abbreviate somewhat the records made upon the cards used for the purpose, and a much smaller card was brought into use on January 1, 1892, thereby greatly facilitating the work of the record room. A further saving was effected by giving the "invoice numbers" only for the packages upon the receipt cards transmitted with the packages, as a means of identification. Attention is called by a printed notice upon the outside of the package to this invoice number, which must be carefully compared with that upon the receipt card, and the latter is to be returned promptly. All these receipts are carefully arranged and filed.

Only by such abbreviation of the records was it possible to carry the exchange work through the year in the face of a curtailed appropriation by Congress. The clerical force was reduced by dropping three clerks and two packers from the roll, though at the end of the year, when the deficiency appropriation became available, a part of the force was temporarily restored, to be again reduced when the fiscal year closed.

Notwithstanding these reductions 4,036 more packages were handled during 1892–'93 than in the previous year, and at the end of June only 73 packages remained on hand.

I take much pleasure in bearing witness to the efficiency of the employés in the exchange office and in expressing appreciation of their efforts to keep up with the added volume of work in spite of the unavoidable reduction in the force to handle it, and I beg leave to call to your notice the careful attention to the interests of the Institution on the part of its special agents abroad, Dr. Felix Flügel, in Leipzig, and Messrs. William Wesley & Son, in London.

Grateful acknowledgments are also due to the following transportation companies and others for their continued liberality in granting the privilege of free freight or in otherwise assisting in the transmission of exchange parcels and boxes, while to other firms thanks are due for reduced rates of transportation in consideration of the disinterested services of the Institution in the diffusion of knowledge.

LIST OF SHIPPING AGENTS AND CONSULS TO WHOM THE EXCHANGE SERVICE IS INDEBTED FOR SPECIAL COURTESIES.

d'Almeirim, Baron, Royal Portuguese consul-general, New York.
American Board of Commissioners for Foreign Missions, Boston.
Anchor Steamship Line (Henderson & Bro., agents), New York.
Atlas Steamship Company (Pim, Forwood & Co.), New York.
Bailey, H. B., & Co., New York.
Börs, C., consul-general for Sweden and Norway, New York.
Boulton, Bliss & Dallett, New York.
Calderon, Climaco, consul-general for Colombia, New York.
Cameron, R. W., & Co., New York.
Baltazzi, X., consul-general for Turkey, New York.
Compagnie Générale Transatlantique (A. Forget, agent), New York.
Cunard Royal Mail Steamship Company (Vernon H. Brown & Co., agents), New York.
Espriella, Justo R. de la, consul-general for Chile, New York.
Hamburg-American Packet Company (R. J. Cortis, manager), New York.
Hensel, Bruckmann & Lorbacher, New York.
Mantez, José, consul-general for Uruguay, New York.
Muñoz y Espriella, New York.

Navigazione Generale Italiana (Phelps Bros. & Co.), New York.
Netherlands American Steam Navigation Company (W. H. Vanden Toorn, agent), New York.
North German Lloyd (agents: Oelrichs & Co., New York; A. Schumacher & Co., Baltimore).
Obarrio, Melchor, consul-general for Bolivia, New York.
Pacific Mail Steamship Company (H. J. Bullay, superintendent), New York.
Pioneer Line (R. W. Cameron & Co.), New York.
Perry, Ed., & Co., New York.
Pomares, Mariano, consul-general for Salvador, New York.
Red Star Line (Peter Wright & Sons, agents), New York and Philadelphia.
Röhl, C., consul-general for Argentine Republic, New York.
Royal Danish Consul, New York.
Ruiz, Domingo L., consul-general for Ecuador.
Stewart, Alexander, consul-general for Paraguay, Washington, D. C.
Toriello, Enrique, consul-general for Guatemala, New York.
White Cross Line of Antwerp (Funch, Edye & Co.), New York.

LIST OF THE CORRESPONDENTS OF THE SMITHSONIAN THROUGH WHOM INTERNATIONAL EXCHANGES ARE TRANSMITTED.

Algeria: Bureau Français des Échanges Internationaux, Paris, France.
Argentine Republic: Museo Nacional, Buenos Ayres.
Austria-Hungary: Dr. Felix Flügel, No. 1, Robert Schumann Strasse, Leipzig, Germany.
Brazil: Bibliotheca Nacional, Rio Janeiro.
Belgium: Commission des Échanges Internationaux, Rue du Musée, No. 5, Brussels.
Bolivia: University, Chuquisaca.
British America: McGill College, Montreal, and Geological Survey Office, Ottawa.
British Colonies: Crown Agents for the Colonies, London, England.
British Guiana: The Observatory, Georgetown.
Cape Colony: Colonial Secretary, Cape Town.
China: Dr. D. W. Doberck, Government Astronomer, Hongkong; for Shanghai: Zi-ka-wei Observatory, Shanghai.
Chile: Museo Nacional, Santiago.
Colombia (U. S. of): National Library, Bogota.
Costa Rica: Instituto Fisico-geográfico Nacional, San Jose.
Cuba: Dr. Frederico Poey, Calle del Rayo, 19, Habana, Cuba.
Denmark: Kongelige Danske Videnskabernes Selskab, Copenhagen.
Dutch Guiana: Surinaamsche Koloniaale Bibliotheek, Paramaribo.
East India: Director General of Stores, India Office, London.
Ecuador: Observatorio del Colegio Nacional, Quito.
Egypt: Société Khédiviale de Géographie, Cairo.
France: Bureau Français des Échanges Internationaux, Paris.
Germany: Dr. Felix Flügel, No. 1, Robert Schumann Strasse, Leipzig.
Great Britain and Ireland: William Wesley & Son, 28 Essex street, Strand, London.
Guatemala: Instituto Nacional de Guatemala, Guatemala.
Guadeloupe: (*See* France.)
Haiti: Secrétaire d'État des Rélations Extérieures, Port-au-Prince.
Honduras: Bibliotheca Nacional, Tegucigalpa.
Iceland: Icelands Stiptisbokasáfn, Reykjavík.
Italy: Biblioteca Nazionale Vittoria Emanuele, Rome.
Japan: Minister of Foreign Affairs, Tokyo.
Java: (*See* Holland,)
Liberia: Liberia College, Monrovia.
Madeira: Director-General, Army Medical Department, London, England.
Malta: (*See* Madeira.)

Mauritius: Royal Society of Arts and Sciences, Port Louis.
Mozambique: Sociedad de Geografia, Mozambique.
Mexico: Packages sent by mail.
New Caledonia: Gordon & Gotch, London, England.
Newfoundland: Postmaster-General, St. Johns.
New South Wales: Government Board for International Exchanges, Sydney.
Netherlands: Bureau Scientifique Central Néerlandais, Den Helder.
New Zealand: Colonial Museum, Wellington.
Norway; Kongelige Norske Frederiks Universitet, Christiania.
Paraguay: Government, Asunçion.
Peru: Biblioteca Nacional, Lima.
Philippine Islands: Royal Economical Society, Manila.
Polynesia: Department of Foreign Affairs, Honolulu.
Portugal: Bibliotheca Nacional, Lisbon.
Queensland: Government Meteorological Observatory, Brisbane.
Roumania: (*See* Germany.)
Russia: Commission Russe des Échanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
St. Helena: Director-General, Army Medical Department, London, England.
San Salvador: Museo Nacional, San Salvador.
Servia: (*See* Germany.)
South Australia: General Post-Office, Adelaide.
Spain: R. Academia de Ciencias, Madrid.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland: Central Library, Bern.
Tasmania: Royal Society of Tasmania, Hobarton.
Turkey: American Board of Commissioners for Foreign Missions, Boston, Mass.
Uruguay: Oficina de Depósito, Reparto y Canje Internacional, Montevedio.
Venezuela: University Library, Caracas.
Victoria: Public Library, Museum and National Gallery, Melbourne.

Transmission of exchanges to foreign countries.

Country.	Date of transmission, etc.
Argentine Republic	February 1; June 17, 30, 1893.
Austria-Hungary	July 12, August 4, 16, September 3, 7, 23, October 7, November 11, 23, December 13, 1892; January 7, February 18, March 15, 22, April 1, 22, May 17, 31, June 7, 26, 1893.
Belgium	August 3, September 6, October 20, 1892; March 27, June 13, 24, 1893.
Bolivia	February 1, 1893.
Brazil	February 1, June 17, 1893.
British Colonies	September 9, October 12, November 15, 1892; January 19, February 25, April 8, 26, May 20, June 5, 27, 1893.
Cape Colony	October 22, 1892; June 22, 1893.
China	September 14, 1892; February 7, June 17, 1893.
Chile	February 1, June 17, 1893.
Colombia	February 1, June 17, 1893.
Costa Rica	February 4, June 20, 1893.
Cuba	February 4, April 10, June 20, 24, 1893.
Denmark	August 9, October 24, 1892; April 28, June 22, 1893.
Dutch Guiana	February 1, 1893.
East India	September 16, 1892; February 9, 1893.
Ecuador	February 1, June 17, 1893.
Egypt	December 23, 1892; June 22, 1893.
France and Colonies	July 14, 21, August 5, 24, September 8, 22, October 10, 22, November 12, 26, December 2, 1892; January 14, February 23, March 1, 13, 24, April 4, 20, May 15, June 2, 29, 1893.

Transmission of exchanges to foreign countries—Continued.

Country.	Date of transmission, etc.
Germany	July 12, 20, August 4, 16, September 3, 7, 23, October 7, November 11, 23, December 5, 13, 1892; January 7, 26, February 17, 18, March 3, 15, 22, April 1, 22, May 17, 20, 31, June 7, 26, 1893.
Great Britain, etc	July 8, 15, 21, August 6, 29, September 9, 28, October 12, November 15, 30, December 8, 1892; January 7, 19, February 25, March 15, 22, April 8. 26, May 20, June 5, 27, 1893.
Guatemala	February 4, June 20, 1893.
Haiti	February 4, June 20, 1893.
Honduras	February 4, June 20, 1893.
Italy	July 19, August 8, September 13, October 13, December 3, 1892; January -, March 16, 24, May 1, June 9, 24, 1893.
Japan	September 14, 1892; June 24, 1893.
Mexico	(By registered mail.)
New South Wales	September 16, December 20, 1892; February 9, April 12, June 19, 1893.
Netherlands and Colonies.	July 22, September 29, 1892; February 16, May 3, June 10, 1893.
New Zealand	September 16, December 20, 1892; February 9, April 12, June 19, 1893.
Nicaragua	February 4, June 20, 1893.
Norway	August 11, October 18, 1892; February 17, June 13, 24, 1893.
Peru	February 1, June 17, 1893.
Polynesia	September 16, December 20, 1892; June 19, 1893.
Portugal	August 11, October 24, 1892; May 23, June 22, 1893.
Queensland	September 16, December 20, 1892; February 9, April 12, June 19, 27, 1893.
Roumania	(Included in Germany.)
Russia	July 15, August 2, September 13, October 17, December 10, 1892; March 17, 24, May 25, June 13, 24, 1893.
San Salvador	February 4, June 20, 1893.
Servia	(Included in Germany.)
South Australia	September 16, December 20, 1892; February 9, April 12, June 19, 1893.
Spain	September 29, 1892; March 24, May 25, June 24, 1893.
Sweden	July 15, August 11, September 13, October 17, December 10, 1892; March, 21, May 25, June 13, 24, 1893.
Switzerland	August 11, October 14, 1892; March 20, 24, May 26, June 24, 1893.
Tasmania	December 20, 1892; February 9, June 19, 1893.
Turkey	June 22, 1893.
Uruguay	February 1, June 17, 1893.
Venezuela	February 1, June 17, 1893.
Victoria	September 16, December, 20, 1892; February 9, April 12, June 19, 1893.

Shipments of U. S. Congressional publications were made on August 22, December 31, 1892, and May 17, 1893, to the governments of the following-named countries:

Argentine Republic.	Colombia.	Netherlands.	South Australia.
Austria.	Denmark.	New South Wales.	Spain.
Baden.	France.	New Zealand.	Sweden.
Bavaria.	Germany.	Norway.	Switzerland.
Belgium.	England.	Peru.	Tasmania.
Buenos Ayres, Province of.	Haiti.	Portugal.	Turkey.
Brazil.	Hungary.	Prussia.	*Uruguay.
Canada (Ottawa).	India.	Queensland.	Venezuela.
Canada (Toronto).	Italy.	Russia.	Victoria.
Chile.	Japan.	Saxony.	Würtemberg.

*Uruguay was added to the list of exchanging governments and on September 27, 1892, the first transmission of 44 cases was made to that country.

The distribution of exchanges to foreign countries was made in 710 cases, representing 242 transmissions as follows:

Argentine Republic	8	Liberia	1
Austria-Hungary	40	Mexico (by mail).	
Belgium	22	New South Wales	10
Bolivia	1	Netherlands	18
Brazil	6	New Zealand	6
British Colonies	11	Nicaragua	2
Cape Colony	3	Norway	10
China	3	Peru	2
Chile	6	Polynesia	4
Colombia	2	Portugal	7
Costa Rica	2	Queensland	11
Cuba	4	Roumania (included in Germany).	
Denmark	8	Russia	34
East India	4	San Salvador	2
Ecuador	2	Servia (included in Germany).	
Egypt	3	South Australia	5
France and Colonies	80	Spain	10
Germany	133	Sweden	21
Great Britain	127	Switzerland	18
Guatemala	2	Tasmania	3
Haiti	2	Turkey	2
Honduras	2	Uruguay	3
Italy	48	Venezuela	2
Japan	11	Victoria	9

RECAPITULATION.

Total Government shipments	168
Total miscellaneous shipments	710
Total shipments	878
Total shipments last year	1,015
Decrease from last year	137

Respectfully submitted.

W. C. WINLOCK,
Curator of Exchanges.

MR. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix IV.

REPORT OF THE ACTING MANAGER OF THE NATIONAL ZOOLOGICAL PARK FOR THE YEAR ENDING JUNE 30, 1893.

Sir: I have the honor to submit the following report of the operations of the National Zoological Park for the fiscal year ending June 30, 1893.

By act of Congress dated August 5, 1892, the sum of $50,000 was appropriated to maintain and improve the park. As no provision was made by this act for the purchase of animals, calculations were made as to the cost of maintaining the collection already on hand and plans for further improvement were based upon the balance then available. The buffalo, elk, and other native wild animals have naturally received the most attention. Effort has been made to place them as far as possible in natural conditions by extending the paddocks assigned to them. While it has not been practicable to give them large ranges, many acres in extent, as was at first intended, since it is now found desirable that they be kept where they can be readily viewed by the public, yet the inclosures are of considerable size. The accompanying engraving represents a group of buffalo now in the Park.

In the preceding year it was necessary to place in the large animal house the animals requiring heat, although that house was still in an unfinished state. During the present year it has been completed, except the outer cages, and a tile roof has been substituted for the temporary one. The plans for the house contemplated additions to the main structure, and as more room was urgently needed and the available funds were insufficient for a stone addition, a frame extension has been built conforming to the original plan in size and form. A row of permanent cages occupies either side of this extension and a large tank in the middle of the room accommodates aquatic animals. By this means it has been possible to give the animals comfortable and suitable quarters where they can be easily seen by the public. It is, however, a matter of great regret that the entire structure was not built of stone and nothing but pressing necessity can excuse the erection of the present extension.

On the meadow upon the right bank of the creek paddocks have been inclosed and a small thatched barn built to shelter a small herd of llamas. These animals were purchased last year in South America through the kindness of Col. W. P. Tisdel, of the Bureau of American Republics.

The plan submitted by the landscape architects provided for a large pond for waterfowl and other aquatic animals at the bend of the creek below the bridge. This pond has been excavated, but fencing and shelters are needed before animals can be put in it.

The principal road through the park was last year completed only to the hill in front of the buffalo house. From this point to the park limit, near Connecticut Avenue Extended, an old wood road had been used, but it was of too steep a grade. A new road has therefore been projected and begun. This road will wind around the spurs of the hill sloping downward toward Rock Creek, bringing to view some of the most beautiful natural scenery of the park, and as it will lead by easy and gradual ascent toward the roads that connect the western entrance with the Woodley road it can not fail to be a favorite and much frequented drive.

There is great need of some easier access to the park than now exists. From the

GROUP OF BUFFALO.
National Zoological Park.

Rock Creek Railway at either end of the park to the animal house is half a mile, and from the Fourteenth street car line a still greater distance. This is a serious inconvenience to many people, particularly the aged and infirm, who have only this means of reaching the park. For carriages the Quarry road is far too narrow and very steep, the grade being 9 per cent in some places.

During the year the District authorities improved this road considerably, properly grading and guttering it and building a suitable sidewalk. While this is a great improvement, the grade of the road is such that it can never be suitable for a principal avenue of access. It is possible that when the projected improvement of Kenesaw avenue is completed that some amelioration of this condition may ensue. There seems to be no reason why street cars should not find ready access to the park by this route.

The unexpected number of visitors made it essential to increase the capacity of the bridge and to protect foot passengers who use it. Footways have accordingly been added to the original structure. These are not wide enough to properly accommodate the public, but are as wide as is consistent with the safety of the structure.

The offices of the park remain in the dilapidated house known as the Holt mansion. When the park was first projected it was expected that the superintendent would reside on the premises, and this building seemed to offer a suitable residence. The experience of the last two years has shown that that plan was a wise one. There should undoubtedly be some one always at hand in the park to respond to any calls that may be made in an emergency. Besides this the park is never closed to the public, and it is therefore desirable that the Superintendent should be always accessible. During the past year several valuable deer have been attacked by dogs during the night and either worried to death or injured so that they had to be killed.

A list of the animals now in the park is herewith submitted, together with statements of those that have been received from various sources. A few animals have been presented, among the most notable being two fine wolf-hounds from Southern Russia by Mr. Byron G. Daniels, U. S. consul at Hull, England; an alligator over 10 feet in length by Mr. E. S. Schmidt, of this city, and a black wolf by Mr. R. M. Middleton, jr., of South Pittsburg, Tenn. These gifts are properly appreciated, yet it is found that increases from such sources can not be depended on to keep up the collection.

From the Yellowstone National Park 17 animals were received. These were kept at that park for some time before shipment, and were then transported by freight, in charge of a keeper. Unless animals can be obtained in greater numbers it will be found that this is a very expensive and precarious method of obtaining them.

A few animals have been loaned, notably a tiger, by Mr. J. T. McCaddon, manager of the Adam Forepaugh shows, and a zebu by Mr. A. E. Randle, of this city. These are subject to recall by their owners. Although such animals do not become the property of the park, yet an opportunity is afforded of exhibiting them for a considerable time for the mere expense of their care and feeding.

The provisions of the appropriation were such that no animals could be purchased during the year, and a number of fine opportunities for acquiring specimens was thus lost.

A few animals were born in the park, among which were a bison, a deer, two elk, and a llama.

The losses by death have been considerable, amounting to as much as 20 per cent of the entire collection.

The total number of animals now on hand is 504, being an increase of 56 over the number on hand at the first of the year.

Animals in the collection June 30, 1893.

Name.	No.	Name.	No.
American bison (*Bison americanus*)	8	American civet-cat (*Bassaris astuta*)	1
Zebu (*Bos indicus*)	2	Raccoon (*Procyon lotor*)	9
Common goat (*Capra hircus*)	3	American badger (*Taxidea americana*)	5
Angora goat (*Capra hircus angorensis*)	1	Black bear (*Ursus americanus*)	4
Llama (*Auchenia glama*)	7	Cinnamon bear (*Ursus americanus*)	3
American elk (*Cervus canadensis*)	9	Grizzly bear (*Ursus horribilis*)	1
Virginia deer (*Cervus virginianus*)	8	Polar bear (*Thalassarctos maritimus*)	2
Mule deer (*Cervus macrotis*)	2	Opossum (*Didelphys virginiana*)	5
Peccary (*Dicotlyes tajacu*)	7	Bald eagle (*Haliæetus leucocephalus*)	1
Indian elephant (*Elephas indicus*)	2	Sparrow hawk (*Falco sparverius*)	1
"Himalayan" rabbit (*Lepus cuniculus*)	1	Red-tailed hawk (*Buteo borealis*)	3
Musk rat (*Fiber zibethicus*)	7	Marsh hawk (*Circus hudsonius*)	1
Coypu (*Myopotamus coypu*)	1	Snowy owl (*Nyctea nivea*)	1
Beaver (*Castor canadensis*)	1	Great horned owl (*Bubo virginianus*)	5
Prairie dog (*Cynomys ludovicianus*)	100	Barred owl (*Syrnium nebulosum*)	1
Striped ground-squirrel (*Spermophilus tridecimlineatus*)	8	Barn owl (*Strix pratincola*)	2
		Screech owl (*Megascops asio*)	2
Chipmunk (*Tamias striatus*)	2	Yellow and blue macaw (*Ara ararauna*)	1
Gray squirrel (*Sciurus carolinensis*)	2	Red and blue macaw (*Ara chloroptera*)	2
Albino gray squirrel (*Sciurus carolinensis*)	1	Red and yellow and blue macaw (*Ara macao*)	1
Red squirrel (*Sciurus hudsonius*)	1	Sulphur-crested cockatoo (*Cacatua galerita*)	1
Crested porcupine (*Hystrix cristata*)	4	Green parrot (*Chrysotis sp.*)	6
Canada porcupine (*Erethizon dorsatus*)	2	Mocking bird (*Mimus polyglottus*)	2
Capybara (*Hydrochœrus capybara*)	1	Common crow (*Corvus americanus*)	7
Paca (*Cœlogenys paca*)	2	Clarke's nutcracker (*Picicorvus columbianus*)	2
Agouti (*Dasyprocta aguti*)	3	Domestic fowl (*Gallus domesticus*) varieties	10
Acouchy (*Dasyprocta acouchy*)	3	Curassow (*Crax alector*)	5
Diana monkey (*Cercopithecus diana*)	1	Pea fowl (*Pavo cristatus*)	10
Grivet monkey (*Chlorocebus engythithea*)	1	Guinea fowl (*Numida meleagris*)	1
Patas monkey (*Chlorocebus ruber*)	1	Bob white (*Colinus virginianus*)	1
Kra monkey (*Macacus cynomolgus*)	1	European quail (*Coturnix communis*)	4
Macaque monkey (*Macacus sp.*)	1	California quail (*Callipepla californica*)	1
Apella monkey (*Cebus apella*)	1	Cariama (*Cariama cristata*)	1
Monk cebus (*Cebus xanthocephalus*)	1	Sand-hill crane (*Grus canadensis*)	2
Black-faced coaita (*Ateles ater*)	1	Black-crowned night heron (*Nycticorax nævius*)	1
Spider monkey (*Ateles grisescens*)	1		
Dourouconli (*Nyctipithecus trivirgatus*)	3	Scarlet ibis (*Guara rubra*)	1
Pinche monkey (*Midas œdipus*)	1	Canada goose (*Branta canadensis*)	4
European hedgehog (*Erinaceus europæus*)	1	Swan (*Cygnus gibbus*)	4
Lion (*Felis leo*)	1	Black swan (*Chenopsis atrata*)	2
Tiger (*Felis tigris*)	1	Chinese goose (*Anser sp.*)	4
Puma (*Felis concolor*)	1	Herring gull (*Larus argentatus*)	1
Ocelot (*Felis pardalis*)	2	Gannet (*Sula bassana*)	2
Wild cat (*Lynx rufus maculatus*)	1	Alligator (*Alligator mississippiensis*)	13
Russian wolf-hound (*Canis familiaris*)	8	Snapping turtle (*Chelydra serpentina*)	2
Black wolf (*Canis occidentalis*)	2	Florida gopher (*Testudo carolina*)	1
Coyote (*Canis latrans*)	2	Mud turtle (*Chrysemys sp.*)	3
Red fox (*Vulpes fulvus*)	7	"Gila monster" (*Heloderma suspectum*)	2
Swift fox (*Vulpes velox*)	6	"Chuck molly" (*Sauromalus ater*)	1
Gray fox (*Vulpes virginianus*)	6	Horned toad (*Phrynosoma douglassii*)	1
Mink (*Putorius vison*)	2	Tiger rattlesnake (*Crotalus tigris*)	1
Ferret (*Putorius furo*)	10	Diamond rattlesnake (*Crotalus adamanteus*)	3
Kinkajou (*Cercoleptes caudivolvulus*)	1	Confluent rattlesnake (*Crotalus confluentis*)	2
Gray coati-mundi (*Nasua narica*)	1	Ground rattlesnake (*Caudisona miliaris*)	1
Red coati-mundi (*Nasua rufa*)	1	Water moccasin (*Ancistrodon piscivorus*)	1

Animals in the collection June 30, 1893—Continued.

Name.	No.	Name.	No.
Copperhead (*Ancistrodon contortrix*)	1	Hog-nosed snake (*Heterodon platyrhinus*)	4
Boa (*Boa constrictor*)	2	South American frogs and toads (unidentified)	14
Anaconda (*Eunectes murinus*)	1	SUMMARY.	
King snake (*Ophibolus getulus*)	2		
Pine snake (*Pityophis sayi*)	1	Indigenous animals	322
Black snake (*Bascanion constrictor*)	2	Foreign animals, not domesticated	87
Garter snake (*Eutænia sirtalis*)	2	Foreign animals, usually domesticated	95
Water snake (*Tropidonotus sipedon*)	10	Total	504

List of accessions.

ANIMALS PRESENTED.

Name.	Donor.	Number of specimens.
Marmoset	C. O. Chenault, New Orleans, La	1
Black wolf	R. M. Middleton, jr., South Pittsburg, Tenn	1
Gray fox	Dr. T. M. Hyneman, Norfolk, Va	1
Do	F. F. Cooper, Staffords Store, Va	1
Do	J. R. Williams, Washington, D. C	1
Do	Jos. Schultz and F. J. Simonds, Washington, D. C	1
Coati-mundi	C. O. Chenault, New Orleans, La	1
Mink	Superintendent Rock Creek Rwy., Washington, D. C	2
Black bear	Lee Kerr and Eugene Pence, Columbia Falls, Mont	1
Do	W. H. McClain, Greenville, Miss	1
Raccoon	R. B. Saunders, Washington, D. C	1
Do		1
Russian wolf-hounds	Hon. B. G. Daniels, U. S. consul at Hull, England	2
Goat	F. M. Thornett, Anacostia, D. C	1
Guinea pig	Otto Haltenorth, Washington, D. C	4
Rabbit	R. B. Clarke, Washington, D. C	2
Himalayan rabbit	H. Burner, Washington, D. C	2
Gray squirrel	F. C. Weaver, Washington, D. C	1
Opossum	J. D. Morey, Washington, D. C	1
Sparrow hawk	W. D. Appich, Alexandria, Va	1
Do	F. L. Thomas, Ashton, Md	1
Red-tailed hawk	G. C. Nichols, Cazenovia, N. Y	1
Marsh hawk	P. W. Skinner, Washington, D. C	1
Snowy owl	Frank Bolles, Chocorua Falls, N. H	1
Great horned owl	do	2
Do	Camm Brothers, Lynchburg, Va	1
Do	J. U. French, Bristersburg, Va	1
Do	Mrs. Carpenter, Washington, D. C	2
Barn owl	Miss J. B. Gray, Fredericksburg, Va	1
Golden-winged woodpecker	M. E. C. Sproesser, Washington D. C	1
Kingfisher	Alice Buckney and Susie Mathews, Washington, D. C	1
Mocking-bird	C. E. Ingersoll, U. S. Fish Commission	1
Common crow	J. F. Edwards, Washington, D. C	1
European quail	Mr. Loeffler, Washington, D. C	4
Virginia quail	B. T. Rhodes, Washington, D. C	1
Pea fowl	Hon. Benjamin Harrison, Washington, D. C	1

List of accessions—Continued.

ANIMALS PRESENTED—Continued.

Name.	Donor.	Number of specimens.
Coot	J. Q. Larmer, Washington, D. C	1
Long-tailed duck	George Schaffer, Alexandria, Va	1
Canada goose	W. H. Green, Washington, D. C	2
Gannet	Taylor Brothers, Washington, D. C	2
Alligator	E. W. Tanner, Washington, D. C	2
Do	J. A. Baker, Washington, D. C	1
Do	E. S. Schmid, Washington, D. C	1
Do	R. P. Carlton, Washington, D. C	3
Florida gopher	D. C. Harrison, U. S. Geological Survey	1
Gila monster	Dr. M. M. Crocker, Gila Bend, Ariz	1
Horned toad	Miss Davis, Washington, D. C	2
Glass snake	Capt. Henry Romeyn, Mount Vernon Barracks, Ala	1
Rattlesnake	W. A. Shoup and J. L. Spear, Spear, Okla	1
Black snake	Harry Salais, Washington, D. C	1
Do	F. S. Watrous, Washington, D. C	2
Hog-nosed snake	J. E. Blascott, Washington, D. C	1
Garter snake	F. C. Watrous, Washington, D. C	2
Water snake	do	3
Do	U. S. Fish Commission	10
		86

ANIMALS RECEIVED IN EXCHANGE.

Name.	Received from.	Number of specimens.
Macaque monkey	E. S. Schmid, Washington, D. C	1
Durukuli monkey	do	2
Black-faced coaita	do	1

Animals born in the National Zoological Park.

American bison (*Bison americanus*)	1
Virginia deer (*Cariacus virginianus*)	1
American elk (*Cervus canadensis*)	2
Russian wolf hounds (*Canis familiaris*)	6
Red fox (*Vulpes fulvus*)	6
Swift or kit fox (*Vulpes velox*)	4
Llama (*Auchenia glama*)	1
Peccary (*Dicotyles tajaçu*)	5
Crested porcupine (*Hystrix cristata*)	1
Opossum (*Didelphys virginiana*)	6

Animals captured in the National Zoological Park.

Opossum (*Didelphys virginiana*)	2
Hog-nosed snake (*Heterodon platyrhinus*)	1
Water snake (*Tropidonotus sipedon*)	1

*Animals obtained by purchase.**

Llama (*Auchenia glama*), through Col. W. P. Tisdel, of the Bureau of American Republics	8

List of animals received from the Yellowstone National Park.

Red fox (*Vulpes fulvus*)	2
Cinnamon bear (*Ursus americanus*)	2
Black bear (*Ursus americanus*)	3
Badger (*Taxidea americana*)	1
Mule deer (*Cariacus macrotis*)	1
American elk (*Cervus canadensis*)	4
Beaver (*Castor canadensis*)	1
Porcupine (*Erethizon dorsatus*)	1

SUMMARY OF ACCESSIONS.

Animals presented		86
Animals loaned		54
Animals received in exchange		4
Animals purchased		8
Animals born in the Zoological Park		80
Animals captured in the Zoological Park		4
Animals received from Yellowstone National Park		15
Total accessions		251
Number of animals on hand June 30, 1892		448
Accessions during the year ending June 30, 1893		251
Total		699
Deduct.		
Deaths	119	
Animals exchanged	47	
Animals returned to owners	29	
		195
Animals on hand June 30, 1893		504

Respectfully submitted.

FRANK BAKER,
Acting Manager.

* These animals were actually purchased during the fiscal year 1891–'92, but did not arrive at the Park until after the beginning of the next fiscal year.

Appendix V.

ASTRO-PHYSICAL OBSERVATORY.

At present the astro-physical observatory is under the immediate direction of the Secretary, but owing to the pressure of other occupations, the conduct of the work in detail has lain largely in the hands of Mr. F. L. O. Wadsworth, who received the appointment of senior assistant on October 10, and to whose efficient aid the Secretary is pleased to acknowledge his obligation.

The general work of the observatory for the year has pertained to the investigation of the infra-red portion of the spectrum, briefly referred to last year, and described in general in the body of my report. It may conveniently be classified under three general heads:

A. General spectro-bolographic work.

B. Special spectro-bolographic work.

C. Instrumental work, including manufacture of new apparatus and the perfection of old.

A. The general bolographic work of the year, (which can be carried on only when the sky is unobscured by clouds or haze), is summed up as follows:

(A "Bolograph" is an *automatic* reproduction of the energy curve, made by the new process.)

	Days available for bolometric work.	Number of bolographs taken.	Character of bolographs.	Remarks.
1892.				
July	10	7		Time mostly occupied by work on wave-length apparatus.
August	1	1	Taken with glass prism	Observatory closed fifteen days.
September	4	10	do	Do.
October	8			Observatory closed ten days.
November	8	23	Glass prism	
December	6	22	do	
1893.				
January	4			Time occupied with grating work.
February	4	8	Grating	Do.
March	13	24	Glass and rock salt	
April	6	14	do	
May	14	40	do	
June	5	27	Rock-salt prism	

SUMMARY:

Total number of days available (*i. e.*, of sunshine days) for bolometric work	83
Total number of bolographs taken:	
(1) With glass prism	114
(2) With rock-salt prism	54
(3) With grating	8
Total	176

Complete records of all of these bolographic curves have been kept in the book specially provided for that purpose, and from them by another automatic process are produced the linear spectra of which an illustration follows. As elsewhere stated, the result of the year's work has been the discovery and approximate determination of position of about 150 or 200 new lines in this hitherto almost unexplored region.

The accompanying illustration of one of the "rock-salt" spectra of the *invisible* spectrum obtained by the new process is intended to give a general, if crude, idea of the novelty, the extent, and (it may be hoped) the value, of this field of labor.

The visible solar spectrum, first investigated by Sir Isaac Newton, is represented as to its length by the blank space on the left; the number .4 (*i. e.*, the part where wave-length is four-tenths of a micron) and .8 (*i. e.*, the part where wave-length is eighth-tenths of a micron) representing the extremities of the solar spectrum as known to him.

Below this all is invisible, and the investigations made at this Observatory by the novel bolometric methods here referred to have been chiefly instrumental in carrying the mapping of lines to 6.0 (six microns), or through nearly thirteen times the extent known to Newton. The great majority of all the lines which fill this space have been discovered and laid down by the new bolometric method, and most of them here in Washington during the last two years.

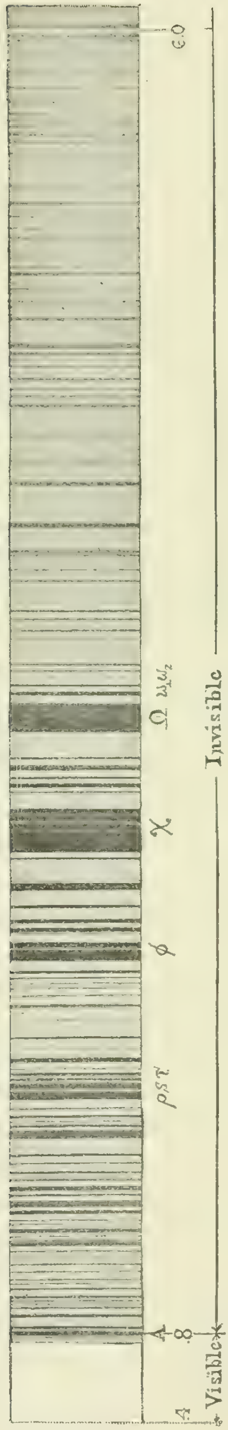
B. The special bolographic work, which is carried on during the cloudy weather, during which the regular work is necessarily interrupted, includes the classification, detailed examination, and, finally, the reduction of the bolographs taken to linear representatives of the infra-red spectrum, in which the final result is a line photograph which is precisely similar, as far as automatic reduction processes will admit, to the line spectrum photographs of the visible part of the spectrum. Owing to the labor involved in this reduction it has been deemed desirable to apply this process of reduction only to the best of the bolographs taken. The result of this portion of the work is briefly summed up as follows:

Line spectrum photographs.

Bolographs reduced for the month of—	Number.	Character of bolograph.	Region represented.
1892.			
July			
August			
September			
October			
November	7	Taken with glass prism	Infra-red spectrum down to wave length $\lambda = 2{\cdot}5\,\mu$.
December	11	do	Do.
1893.			
January			
February			Infra-red spectrum down to wave length $\lambda = 2{\cdot}5\,\mu$.
March	10	Taken with glass prism	Do.
April	3	Taken with rock salt prism	Infra-red spectrum down to wave length $\lambda = 5\,\mu$.
May	3	do	Do.
June	5	do	Do.

Total from glass prism	28
Total from rock salt prism	11
Aggregate	39

These represent complete line spectrum charts of the invisible portion of the spectrum down to about $2{\cdot}5\,\mu$ for the glass and $5\,\mu$ for the rock salt prism.



Map of the spectrum.

While this number seems small in comparison with the whole number of bolographs taken, it nevertheless represents even more work. In this particular work the history of the year is one of continual change and improvement and many of the bolographs of the earlier part of the year have been reduced by three different processes, each of which involves three distinct photographic steps, and in consequence the 39 final line spectrum photographs stand for more than 200 finished photographs, and as many more which are experimental.

After a large amount of experimental work, a process has finally been perfected which is fairly satisfactory, and has been adopted provisionally as a working method. Experiments, however, are still in progress with a view to further modification and improvement.

In addition to this bolometric work proper, experiments on three special methods of investigation of the infra-red spectrum, have formed a considerable portion of the year's work:

(1) Preliminary experiments on the measurement of wave-lengths in the invisible spectrum by interference methods.

(2) Experiments on photographing the invisible spectrum by the aid of phosphorescent films.

(3) Preliminary experiments on bolometric investigation of the infra-red normal (grating) spectrum.

I. During the month of July, 1892, a series of preliminary experiments was made on a method of measurement of wave-lengths in the invisible spectrum, with special reference to the establishment of a few datum points with great accuracy. The apparatus employed for this purpose, which was kindly lent by Clark University, was a modification of the inferential wave comparer used with so much success by Prof. Michelson, in the establishment of a wave-length standard.

As the method of working was entirely new, considerable time was required to put the apparatus in working order. Some preliminary results were obtained in the region just above "A," by Mr. Wadsworth, in whose hands I placed it, but the work was interrupted by his departure for Paris, and has not since been resumed. The accuracy and practicability of this method of determining wave-lengths has, however, been demonstrated, and it is hoped time will be found in the near future to continue this work.

II. During the month of October I made a number of experiments to determine the practicability of photographing the infra-red spectrum directly with the aid of phosporescent films.

After considerable experimentation on the best method of working, a number of photographs of the invisible portion of the spectrum extending as far as wave-length 1·5 μ were thus obtained. Although the detail is very much less than that obtained by the bolometer, the method is valuable in furnishing a general check on the results of the more analytical method. With greater care in the preparation of films, still better resuls could be obtained. Other films sensitive to heat rays were tried, particularly those containing a salt of mercury, but without adequate results.

III. During the winter months of January and February, in which regular bolometric work was almost entirely interrupted by bad weather, attention was devoted to the theoretical investigation of a method of bolometrically investigating the normal grating spectrum, the essential feature of which was the employment of a "lifting" prism, by the use of which the superposed spectra were to be avoided.

After determination of the best instrumental conditions, provisional apparatus was constructed and installed, and a few experimental bolographs taken. The approach of good observing weather then necessitated its removal. A paper describing the method and containing the essential results of the investigation of the instrumental conditions has been prepared for publication.

C. What might almost be said to have been the chief work of the Observatory for the year has been the improvement of the apparatus and instrumental conditions of working.

The lines of development have been: (1) In the increase of delicacy; (2) in the increase of stability and accuracy.

With a view to increased delicacy much time has been devoted through the year to the improvement of the galvanometer.

During the absence in Europe of the present senior assistant, he, by my direction, devoted two weeks exclusively to this work, and the elements of three galvanometers were constructed after his design, two by Nalder Bros. and one by Elliott Bros. After his return, the work of improvement of my earlier designs for the old galvanometer and of the new ones was at once begun. Pending the completion of the new galvanometers, the improvement of the three old ones already in use was undertaken, and the delicacy of each was more than doubled. Up to date only one of the new galvanometers has been completed, and this owing to the introduction of an almost unprecedentedly light, magnetic system, and through other improvements, has been found to be about 35 times more delicate than the best of these previously in use.

This degree of delicacy will, it is probable, be exceeded by one of the two remaining forms, but lack of time has prevented further improvement at present. Indeed the conditions of use at present are such as to render only about one-tenth of this increased delicacy available, and only a new laboratory will enable the full increase of delicacy to be perfectly utilized.

An abbreviated statement of the galvanometer work for the year is appended:

Galvanometer.	Description.	Old constant.*	New constant (after improvement).
(Old)	D'Arsonval	0·0000001000	·0000000200
White (old) Alleghany pattern	Thomson	0·00000000150	·00000000070
Queen (old)	do	0·00000000160	·00000000040
Elliott Bros. special design new	do		·00000000004
Nalder Bros. special design new	Thomson (multiple)†		·00000000002
Do	D'Arsonval		Not finished.

*Current which deflects image one millimetre at distance of 1 metre, when the time of a single vibration is 10 seconds.

†Partially finished.

For use in these new galvanometers, the laboratory has received during the year, a lot of very fine quartz fibers, made to special order by Prof. C. C. Hutchins, and some very small, light, and accurate concave mirrors from J. A. Brashear, the use of which in the new galvanometer has been already referred to. A very considerable improvement in the mechanical steadiness of this part of the apparatus has also been effected by mounting the whole galvanometer in a massive metal case, which rests on a series of stone blocks placed one above another and separated from each other by sheets of rubber. In spite of these precautions, the vibrations due to passing teams and wagons are at times still very troublesome.

(2) The improvement in the other parts of the apparatus has been mainly in the direction of increased accuracy. The siderostat has been provided with a new electric control, by means of which inaccuracies of running may be quickly compensated for from inside the building. Considerable improvement has also been effected in the minor parts of the instrument, but it still needs to be thoroughly overhauled. The changes for which there is most pressing need are the remounting of the equatorial axis on ball bearings and the construction of a new governor for the clock.

The spectro-bolometer and its accessories is that part of the train of apparatus which has undergone the most radical change. The principal changes which have been made in its construction and working during the past year are:

(1) The adoption of a reflecting mirror secured to the prism and revolving with it, which has rendered it possible to fix both the spectro-bolometer slit and the bolometer itself in position, thereby avoiding the use of a long revolving arm.

This device permits of indefinite extension of the bolometer arm, and consequently the reduction of the angular value of the bolometer strip to a very minute quantity.

(2) The provision of a new adjustable tangent arm for slowly rotating the axis of the spectro-bolometer with great accuracy.

(3) The adoption of a new system of clock-work for synchronously driving this tangent arm, and the photographic plate on which the galvanometer record is taken, in place of the two independent driving clocks before used.

(4) The mounting of all parts of the spectro-bolometer on rigid iron or stone supports.

The improvements in the method of working which have accompanied these improvements in apparatus are:

(1) The substitution of glass plates for flexible films for the photographic records. The irregular errors due to shrinkage of the film have thus been eliminated and the subsequent photographic processes rendered much easier by reason of the greater facility of handling.

(2) The reduction, and in some cases almost entire elimination, of the "drift" by the use of a water-jacket about the fixed bolometer case, together with careful attention to all the electrical details of the bolometer and galvanometer connections, and the substitution of storage battery cells for the Daniel cells, formerly used to supply the current to the bridge circuit. The "drift," however, still remains a source of great trouble and I expect to secure its elimination only (if at all) by the establishment of uniform temperature conditions, which it is impossible to obtain in the present laboratory (at least during the summer months).

The laboratory building itself has been considerably improved during the past year. A small annex, which is used as a photographic dark room, was erected in the spring of 1893, and has greatly facilitated the photographic work of the observatory. During the summer a small air-cooling plant was placed in the basement, and served not only to increase the comfort of the observers, but also to secure more favorable conditions for the work then being carried on with rock salt.

During the past year the observatory also fitted up a small instrument shop for the construction and repair of its apparatus, comprising an instrument-maker's lathe, built to my special order, a small planer from the Hendley Machine Company, and a fairly complete stock of small tools, and stock material. A dynamo, for supplying current to the observatory for charging the storage batteries and to the shop for power purposes, was also purchased and temporarily placed in the National Museum. Owing to the lack of suitable quarters the shop has not yet been permanently located, but occupies a temporary shed south of the Smithsonian building.

The important pieces of apparatus acquired during the year may be divided into two general classes: (1) Physical apparatus of precision; (2) accessory apparatus.

I. To the former class belongs:

(1) Three new galvanometers and sets of galvanometer coils from Elliott Brothers and Nalder Brothers.

(2) Resistance boxes one of 100,000 ohms and one of 1,000 ohms from Nalder Brothers.

(3) A set of fine quartz fibers, from Prof. C. C. Hutchins.

(4) Six fine galvanometer mirrors, from J. A. Brashear.

(5) One large glass prism, from J. A. Brashear.

(6) Two large glass lenses, from J. A. Brashear.

(7) Two new large rock salt lenses, from M. E. Kahler.

(8) A collection of valuable rock salt crystals, from Germany.

(9) Three new $\frac{1}{20}$-milometer bolometers, from Grunow.

(10) One large 24-inch camera, a fine Ross lens, and a complete photographic outfit, from Scoville & Co.

(11) A new tangent arm for spectro-bolometer, from J. A. Brashear.

(12) A new prism holder, with large glass flat, from J. A. Brashear.

II. Accessory apparatus:

(1) A complete instrument-maker's lathe, with outfit of tools and chucks.

(2) A 30-inch hand and power planer for metal work, with chuck, etc., from the Hendley Machine Company.

(3) A 40-light incandescent dynamo, with rheostats, etc., from Westinghouse Electric Company.

(4) A one-half horse power motor, from Akron Electric Company.

(5) A one-fourth horse-power water motor and Sturtevant pressure fan, with accessory apparatus for cooling the air of the Observatory.

The total value of the apparatus purchased during the year was about $3,000.

MINOR WORK OF THE YEAR.

In addition to Mr. Wadsworth's work with Prof. Michelson in the establishment of the length of the standard meter in terms of the wave length of light, at the International Bureau of Weights and Measures, reference to which has already been made, the following special work, which has been done during the year, may be mentioned:

(1) The preparation of a complete series of line-shaded drawings of the principal pieces of apparatus in the observatory on a scale requisite to show their detailed construction.

(2) The preparation of a series of enlargements of moon photographs from the Kenwood and Lick observatories, photographs.

(3) Experiments in temperature and radiation work.

During the latter part of the year preliminary experiments were begun and carried on at intervals looking to the systematic preparation for another extended research, which I have proposed to soon begin to determine the physical relation between temperature and radiation. The experiments have mostly been directed to the establishment of a satisfactory source of temperature and means of measuring the same. The various apparatus, etc., for the prosecution of this work at an early date has either been ordered or already installed.

(4) Some further attempts have been made at solar photography, but, as the experience of last year conclusively showed, the atmospheric conditions here in the city are very unfavorable to any satisfactory work in this direction.

PERSONNEL.

The force of the Observatory consists of a Senior assistant, and an instrument-maker, and an assistant instrument-maker. During the past year the Observatory has also had at different times special assistants, among whom I wish to acknowledge the assistance of Mr. J. G. Hubbard, to whose photographic skill several improvements of this part of the work are due.

Appendix VI.

REPORT OF THE LIBRARIAN FOR THE YEAR ENDING JUNE 30, 1893.

Sir: I have the honor to submit herewith a report upon the operations of the library of the Smithsonian Institution during the fiscal year ending June 30, 1893.

The work of recording accessions has been conducted as in the preceding years. The entry numbers in the accession book extend from 246, 110 to 268, 386.

The following table shows the number of volumes, parts of volumes, pamphlets, and charts received during the year:

Publications received between July 1, 1892, and June 30, 1893.

	Quarto or larger.	Octavo or smaller.	Total.
Volumes	594	1,245	1,839
Parts of volumes	16,650	6,299	22,949
Pamphlets	870	3,581	4,451
Charts			249
Total			29,488

Of these publications, 272 volumes, 6,981 parts of volumes, and 821 pamphlets, 8,074 in all, were retained for use in the U. S. National Museum.

Nine hundred and sixty-three medical dissertations were deposited in the library of the Surgeon-General U. S. Army; the remaining publications were sent to the Library of Congress on the Monday after their receipt.

In carrying out the plan formulated by the Secretary for increasing the library by exchanges, 781 letters asking for publications not on our list, or asking for numbers to complete the series already in the library, have been written. It gives me pleasure to report that as a result of this correspondence 246 new exchanges were acquired by the Institution, while 81 defective series were completed, either wholly or as far as the publishers were able to supply missing parts.

Since this plan of the Secretary was first formulated in 1887, 4,512 letters have been written with a view of increasing the number of periodicals and transactions of learned societies in the library of the Smithsonian Institution. The result of this work has been most gratifying; 1,350 new periodicals have been added to the list and 909 defective series have been either completed or filled out as far as the publishers were able to supply missing parts.

The reading room is now taxed to its utmost capacity; the 494 boxes for the use of scientific periodical literature are all filled and periodicals which it would be desirable to keep in the general reading room must be placed elsewhere for lack of space. The reading room no longer has sufficient accommodations for the growing exchanges of the Institution nor for the persons desiring to consult this important collection of current scientific literature.

Ever since 1890 the Secretary has called attention in his annual report to the fact that the present quarters of the library are insufficient; the natural expansion of the library has been prevented by the fact that the rooms adjacent to the library were occupied by the bureau of international exchanges. It will be possible shortly to assign other quarters to the bureau of international exchanges, and plans have been prepared for book shelves in one of the rooms made vacant. It is estimated that space will thus be secured for about 6,000 volumes.

In addition to the strictly scientific literature which is contained in the reading

room, the literary magazines are also on file and their use by the officers and employés of the Institution and the National Museum is constantly increasing.

Below is a comparative statement of the operations of the library since June 30, 1890:

Number of publications received.

	1890-'91.	1891-'92.	1892-'93.
Volumes	2,681	1,989	1,839
Parts of volumes	20,525	23,729	22,949
Pamphlets	3,769	3,589	4,449
Charts	319	621	249
Total	27,294	29,928	29,488

It will be observed that this comparative table shows a slight decrease in the number of publications received during the current year over the preceding year. The decrease, however, is in volumes, and is due to the fact that the limit of the possibility of completing series of publications by exchange, seems to have been reached.

The number of titles for the past year shows an increase of almost 2,000 over that of the year preceding.

The following table shows the number of titles received per year for the past six years:

Number of titles received.

1887-'88	12,105
1888-'89	11,370
1889-'90	13,474
1890-'91	18,409
1891-'92	20,523
1892-'93	22,276

It will be seen from the above table that the number of titles received by the library has almost doubled since 1887, a gratifying fact, yet one which severely taxes the library force in the recording and arrangement of the material received.

No fewer than 4,087 acknowledgments of publications were made by the post card and other printed forms, while many gifts were acknowledged by special letter.

The following universities have sent complete sets of their academic publications, including inaugural dissertations:

Basel,
Berlin,
Bern,
Bonn,
Breslau,
Dorpat,
Erlangen,
Freiburg, Br.,
Giessen,
Greifswald,
Halle, A. S.,
Heidelburg,
Helsingfors,
Jena,
Johns Hopkins,
Kiel,
Königsberg,
Leipzig,
Louvain,
Lund,
Marburg,
Strasburg,
Tübingen,
Utrecht,
Wurzburg,
Zurich.

On July 1, 1892, Mr. J. Elfreth Watkins was appointed Assistant in charge of the library, a position which he held until the first of October. From that date until December 1, Mr. N. P. Scudder was acting Librarian.

Very respectfully, yours,

CYRUS ADLER,
Librarian.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

APPENDIX VII.

REPORT OF THE EDITOR FOR THE YEAR ENDING JUNE 30, 1893.

SIR: I have the honor to submit the following report upon the publications of the Smithsonian Institution for the year ending June 30, 1893:

I. SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

Of the Volume XXVII of the quarto series of "Contributions" (having the serial No. 839 in the Smithsonian list of publications) only a part has yet been issued, namely, No. 801, "Experiments in Aerodynamics," By S. P. Langley. This was included in last year's list of publications.

No. 840. "Life Histories of North American Birds, with special reference to their breeding habits, and eggs; with twelve lithographic plates." By Charles Bendire. Quarto volume of x+446 pages: illustrated with 12 plates of 185 chromo-lithographic figures of birds' eggs.

No. 841. "Smithsonian Contributions to Knowledge. Volume XXVIII." This volume is entirely occupied with the "Life Histories of American Birds," etc., just above described. Agreeably to the established practice of the Institution, a separate edition of 250 copies of the work has been issued as No. 840, for special distribution to those more particularly interested in the subject, the principal edition of 1,000 copies being designed for deposit with the leading scientific societies and public libraries, in continuation of the series of "Contribution" volumes. With the extra title-page and preliminary matter this volume comprises xxi+446 pages, illustrated with 12 chromo-lithographic plates.

No. 842. "The Application of Interference Methods to Spectroscopic Measurements, with five plates." By Albert H. Michelson. Quarto volume of 24 pages; illustrated with 5 plates.

II. SMITHSONIAN MISCELLANEOUS COLLECTIONS.

No. 843. "The Mechanics of the Earth's Atmosphere. A collection of Translations, by Cleveland Abbe." Octavo volume of 324 pages; illustrated with 46 figures.

No. 844. "Smithsonian Meteorological Tables." Octavo volume of lix+262 pages. This work will form the first part of Volume XXXV of the "Miscellaneous Collections," which volume is not yet completed.

No. 849. "Smithsonian Miscellaneous Collections, Volume XXXIV." This volume contains: Article 1, The Toner Lectures. Lecture IX.—Mental Overwork and Premature Disease among Public and Professional Men. By Charles K. Mills, M. D., January, 1885. Article 2, Transactions of the Anthropological Society of Washington, Volume III, November 6, 1883—May 19, 1885, 1886. Article 3, Index to the Literature of Columbium, 1801–1887. By Frank W. Traphagen, PH. D., 1888. Article 4, Bibliography of Astronomy for the year 1887. By William C. Winlock, 1888. Article 5, Bibliography of Chemistry for the year 1887. By H. Carrington Bolton, 1888. Article 6, The Toner Lectures. Lecture X.—A clinical study of the skull. By Harrison Allen, M. D., March, 1890. Article 7, Index to the Literature of Thermodynamics. By Alfred Tuckerman, PH. D., 1890. Article 8, The Correction of Sextants for Errors of Eccentricity and Graduation. By Joseph A. Rogers, 1890. Article 9, Bibliography of the Chemical Influence of Light. By Alfred Tuckerman, PH. D., 1891. Article 10, The Mechanics of the Earth's Atmosphere. A collection

of Translations, by Cleveland Abbe, 1891. The whole forms a volume of v+1054 pages: illustrated with 69 figures.

No. 850. "A Select Bibliography of Chemistry, 1492-1892." By Henry Carrington Bolton. Octavo volume of xiii+1212 pages.

No. 851. "Smithsonian Miscellaneous Collections. Volume XXXVI." This volume consists of a single work: the "Select Bibliography of Chemistry" just above described, 250 copies of the bibliography having been issued as an independent book, and 1,000 copies (with additional title page) as the 36th volume of the "Miscellaneous" series, for libraries and societies. Octavo volume of xviii+1212 pages.

No. 852. Tables of natural sines and co-sines, tangents and co-tangents, together with useful physical constants, etc. Octavo pamphlet of 8 pages.

III.—SMITHSONIAN ANNUAL REPORTS.

No. 845. "Report of S. P. Langley, Secretary of the Smithsonian Institution, for the year ending June 30, 1892," to the Regents of the Institution. Octavo pamphlet of iii+83 pages. Illustrated with 5 figures.

No. 846. "Report of the National Museum, annual report of the Board of Regents of the Smithsonian Institution, showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1890." This volume comprises five sections: I. Report of the assistant secretary of the Smithsonian, G. Brown Goode, in charge of the National Museum, upon the condition and prospect of the Museum; II. Reports of the curators of the National Museum upon the progress of work during the year; III. Papers describing and illustrating the collections in the Museum; IV. Bibliography of publications and papers relating to the Museum during the year; and V. List of accessions to the Museum during the year. The whole forms an octavo volume of xviii+811 pages, illustrated with 163 plates and 99 figures.

No. 848, the Smithsonian report to July 1, 1891, and No. 853, the Museum report to July 1, 1891, have not yet been received from the Public Printer.

IV. REPORTS OF THE BUREAU OF ETHNOLOGY.

No. 847. "Seventh Annual Report of the Bureau of Ethnology to the Secretary of the Smithsonian Institution, 1885, 1886:" By J. W. Powell, Director. This volume contains the introductory report of the director (27 pages), together with accompanying papers, to wit: "Indian Linguistic Families of America north of Mexico," by J. W. Powell; "The Midewiwin or 'Grand Medicine Society' of the Ojibwa," by W. J. Hoffman; "The sacred Formulas of the Cherokees," by James Mooney. A royal-octavo volume of xliii + 409 pages; illustrated with 39 figures in the text, and 26 plates, of which 2 are maps, and 6 are chromo-lithographs.

Respectfully submitted.

W. B. TAYLOR,
Editor.

Mr. S. P. LANGLEY.
Secretary of the Smithsonian Institution.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1893.

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law, with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the Secretary, induced in part by the discontinuance of an annual summary of progress which for thirty years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoölogy, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report, for 1893.

THE WANDERINGS OF THE NORTH POLE.*

By Sir Robert Ball, F. R. S.

On a recent visit to Cambridge, Prof. Barnard, the discoverer of the fifth satellite of Jupiter, exhibited at the Cavendish Laboratory his most interesting collection of photographs made at the Lick Observatory. These pictures were obtained by a 6-inch photographic lens of 3 feet focus, attached to an ordinary equatorial, the telescope of which was used as a guider when it was desired to obtain a picture of the stars with a long exposure. Among the advantages of this process may be reckoned the large field that is thereby obtained, many of the plates that he exhibited being as much as 4 degrees on the edge. I am however not now going to speak of Barnard's marvellous views of the milky way, nor of the plate on which a comet was discovered, nor of the vicissitudes of Holmes's comet, nor of that wonderful picture in which Swift's comet actually appears to be producing, by a process of gemmation, an offshoot which is evidently adapted for an independent cometary existence. The picture to which I wish specially to refer in connection with our immediate subject is one in which the instrument was directed towards the celestial pole. In this particular case the clock-work which is ordinarily employed to keep the stars acting at the same point of the plate was dispensed with. The telescope, in fact, remained fixed while the heavens rotated in obedience to the diurnal motion. Under these circumstances each star, as minute after minute passed by, produced an image on a different part of the plate, the consequence of which was that the record which the star was found to have left, when the picture was developed, was that of a long trail instead of a sharply defined point. As each star appears to describe a circle in the sky around the pole, and as, in the vicinity of the pole, these circles were small enough to be included in the plate, this polar photograph exhibits a striking spectacle. It displayed a large number of concentric circles, or rather, I should say, of portions of circles, for the exposures having lasted for about four hours, about one-sixth of each circumference was completed during that time.

* From the *Fortnightly Review,* August, 1893; vol. LIV, pp. 171-183.

The effect thus produced was that of a number of circular arcs of varying sizes and of different degrees of brightness. Most conspicuous amongst them was the trail produced by the actual polar star itself. It is well known, of course, that though the situation of the pole is conveniently marked by the fortunate circumstance that a bright star happened during the present century to lie in the immediate vicinity of the veritable pole, yet, of course, this star is not actually at the pole, and consequently, like all the other stars, Polaris itself must be revolving in a circle whereof the center lies at the true pole. The brighter the star the brighter is the trail which it produces, so that the circle made by Polaris is much more conspicuous than the circles produced by the other stars of inferior luster. It is however to be noted that some of the faint stars lie much closer to the pole than Polaris itself. There is indeed one very minute object so close to the pole that the circle in which its movements are performed seems very little more than a point when represented on the screen on which the slide was projected. The interesting circumstance was noted that there appeared to be occasional interruptions to the continuity of the circular arcs. This was due to the fact that clouds had interposed during the intervals represented by the interruptions. A practical application is thus suggested, which has been made to render useful service at Harvard College Observatory. Every night, and all night long, a plate is there exposed to this particular part of the sky, and the degree in which the Pole-star leaves a more or less complete trail affords an indication of the clearness or cloudiness of the sky throughout the course of the night. From the positions of the parts where the trail has been interrupted it is possible not only to learn the amount of cloudiness that has prevailed, but the particular hours during which it has lasted. This interesting system of concentric polar circles affords us perhaps the most striking visual representation that could possibly be obtained of the existence of that point in the heavens which we know as the pole. The picture thus exhibited was a striking illustration of the Copernican doctrine that the diurnal stellar movement was indeed only apparent, being of course due to the rotation of the earth on its axis.

Suppose that a photograph, like that I have been describing, were to be taken at intervals of a century, it would be found that the center of the system of circles, that is to say, the veritable pole itself, was gradually changing on the heavens. I do not by this mean that the stars themselves would be found to have shifted their places relatively to each other. No doubt there is some effect of this kind, but it is an insignificant one, and need not at present concern us. The essential point to be noticed is, that the stars which happen to lie in the vicinity of the pole would have a changed relation to the pole in consequence of the fact that this latter point is itself in incessant movement. At the present time the pole is advancing in such a direction that it is getting nearer to the Pole-star, so that the actual circle which the Pole-

star is describing is becoming less and less. The time will come when the circle which this star performs will have reached its lowest dimensions, but still the pole will be moving on its way, and then, of course, the dimensions of the circle traversed by the Pole-star will undergo a corresponding increase. As hundreds of years and thousands of years roll by the pole will retreat farther and farther from the Pole star, so that in the course of a period as far on in the future as the foundation of Rome was in the past, the pole will be no longer sufficiently near the Pole-star to enable the latter to render to astronomers the peculiar services which it does at present.

Looking still farther ahead, we find that in the course of about twelve thousand years the pole will have gained a position as remote as it possibly can from that position which it now occupies. This most critical point in the heavens will then lie not far from the star Vega, the brightest point in the northern sky, and then it will commence to return, so that after the lapse of about twenty-five thousand years the pole will be found again in the same celestial neighborhood where it is to-night, having, in the meantime, traversed a mighty circle through the constellations. In all this there is no novelty; these movements of the pole are so conspicuous that they were detected long before the introduction of accurate instruments. They were discovered so far back as the time of Hipparchus, and the cause of them was assigned by Newton as one of the triumphs of his doctrine of universal gravitation. In giving the title of "The Wanderings of the North Pole" to this paper I did not however intend to discourse of the movements to which I have hitherto referred. They are so familiar that every astronomer has to attend to them practically in the reduction of almost every observation of the place of the celestial body. It was however necessary to make the reference which I have done to this subject in order that the argument on which we are presently to enter should be made sufficiently clear. It must be noted that the expression "the North Pole" is ambiguous. It may mean either of two things, which are quite distinct. In the case we have already spoken of, I understand by the North Pole that point on the celestial sphere which is the center of the system of concentric circles described by the circumpolar stars. The other sense in which the North Pole is used is the terrestrial one; it denotes that point on this earth which has been the goal of so many expeditions, and to reach which has been the ambition of so many illustrious navigators. We have a general notion that the terrestrial North pole lies in a desolate region of eternal ice, somewhat relieved by the circumstance that for six months of the year the frozen prospect is brightened by perpetual day, though on the other hand, during the remaining six months of the year this region is the abode of perpetual night.

The North Pole is that hitherto unattainable point on our globe on which, if an observer could take his station, he would find that the

phenomena of the rising and the setting of the stars, so familiar elsewhere, were non-existent. Each star viewed from the coign of vantage offered by the North Pole would move round and round in a horizontal circle, and the system of concentric circles would be directly overhead. In midsummer the sun would seem to revolve around, remaining practically at the same elevation above the horizon for a few days, until it slowly began to wend its way downwards in a spiral. In a couple of months it would draw near the horizon, and as day after day passed by the luminary would descend lower and lower until its edge grazed the horizon all round. The setting of the sun for the long winter would then be about to commence, and gradually less and less of the disk would remain perceptible. Finally the sun would disappear altogether, though for many days afterwards a twilight glow would travel round the whole hemisphere, ever getting less and less, until at last all indications of the sun had vanished. The utter darkness of winter would then ensue for months, mitigated only so far as celestial luminaries were concerned by starlight or occasional moonlight. Doubtless, however, the fitful gleams of the aurora would often suffice to render the surrounding desolation visible. Then as the spring drew near, if, indeed, such a word as spring be at all applicable to an abode of utter dreariness, a faint twilight would be just discernible. The region thus illuminated would move round and round the horizon each twenty-four hours, gradually becoming more and more conspicuous, until at last the edge of the sun appeared. Then, by a spiral movement inverse to that with which its descent was accomplished, the great luminary would steal above the horizon, there to continue for a period of six months until the commencement of the ensuing winter. Indeed, the actual duration of apparent summer would be somewhat protracted in consequence of the effect of refraction in raising the sun visually above the horizon when in reality it was still below. The result would be to lengthen the summer at one end and to anticipate it at the other. Such would be the astronomical conditions of the North Pole; that anomalous point, from whence every other locality on the globe lies due south, that mysterious point which up to the present seems never to have been approached by man within a distance less than 400 miles, unless, indeed, as is not improbably the case, the pre-glacial man who lived in the last genial period found a temperate climate and enjoyable conditions even at the latitude of 90°.

For our present purpose it will be necessary to get a very clear idea as to the precise point on the earth which we mean when we speak of the North Pole. As our knowledge of it is almost entirely derived from astronomical phenomena, it is necessary to assign the exact locality of the pole by a strict definition depending on astronomical facts. Supposing that Nansen does succeed in his expedition, as everyone hopes that he will, and does penetrate within that circle of 400 miles radius where the foot of civilized man has never yet trod, how is he to identify

that particular spot on this globe which is to be defined by the North Pole? It was for this purpose that at the commencement of this paper I referred to that photograph of the concentric circles which illustrated so forcibly the position of the pole in the heavens. Imagine that your eye was placed at the center of the earth, and that you had a long slender tube from that center to the surface through which you could look out at the celestial sphere; if that tube be placed in such a way that, when looking from the center of the earth through this tube, your vision was directed exactly to that particular point of the heavens which is the center of the circle now described by the Pole Star and the other circumpolar stars, then that spot in which the end of the tube passes out through the surface of the earth is the North Pole. Imagine a stake to be driven into the earth at the place named, then the position of that stake is the critical spot on our globe which has been the object of so much scientific investigation and of so much maritime enterprise. The reader must not think that I am attempting to be hyper-accurate in this definition of the North Pole; no doubt, in our ordinary language we often think of the pole as something synonymous with the polar regions, an ill-defined and most vaguely known wilderness of ice. For scientific purposes it is, however, essential to understand that the pole is a very definitely marked point, and we must assign its position accurately, not merely to within miles, but even to within feet. Indeed, it is a truly extraordinary circumstance that, considering no one, with the possible exception just referred to, has ever yet been within so many hundred miles of the pole, we should be able to locate it so precisely that we are absolutely certain of its position to within an area not larger than that covered by a small town, or even by a good sized drawing room.

We have seen that the North Pole in the sky is in incessant movement, and that the travels which it accomplishes in the course of many centuries extend over a wide sweep of the heavens; this naturally suggests the question, Does the pole in the earth move about in any similar manner, and if so, what is the nature and extent of its variation? Here is the point about which those modern researches have been made which it is my special object to discuss in this paper. Let us first see clearly the issue that is raised. At the time of the building of the Pyramids the pole in the heavens was in quite a different place from its present position; the Pole Star had not at that time the slightest title to be called a pole star; in fact, the point around which the heavens revolved lay in a wholly different constellation. It was certainly not far from the star *Alpha Draconis* about 3000 B. C., and we could indicate its position quite definitely if we had any exact knowledge as to the date of the Pyramids' erection. It is, however, plain that the difference was so patent between the celestial pole at the time of the Pyramids and the celestial pole of later centuries, that it could not be overlooked in attentive observation of the heavens. As the North

Pole in the sky was, therefore, so different in the time of the Pharaohs from the North Pole in the time of Victoria, it is proper to ask whether there was a like difference, or any difference at all, between the terrestrial pole at the time of the building of the Pyramids and that terrestrial pole in whose quest Nansen is just setting off. If Pharaoh had despatched a successful expedition to the North Pole and driven a post in there to mark it, and if Nansen were now successful, would he find that the North Pole in the earth which he was to mark occupied the same position or a different position from that which had been discovered thousands of years previously? At first one might hastily say that there must be such a difference, for it will be remembered that I have defined the North Pole in the earth as that point through which the tube passes which would permit an eye placed at the center of the earth to view the North Pole in the sky. If, therefore, the North Pole in the sky had undergone a great change in its position, it might seem obvious that the tube from the earth's center to its surface which would now conduct the vision from that centre to the north celestial pole would emerge at a different point of the earth's crust from that which it formerly occupied. We have here to deal with the case that arises not unfrequently in astronomy, in which a fact of broad general truth requires a minute degree of qualification; indeed, it is not too much to say that it is in this qualification of broad general truths that many of the greatest discoveries in physical science have consisted. And such is the case in the present instance. There is a broad general truth and there is the qualification of it. It is the qualification that constitutes the essential discovery which it is my object herein to set forth. But before doing so it will be necessary for me to lay down the broad general truth that the North Pole of the earth as it existed in the time of the Pharaohs appears to be practically the same as the North Pole of the earth now. It seems perfectly certain that at any time within the last ten thousand years the North Pole might have been found within a region on the earth's surface not larger than Hyde Park. Indeed, the limits might be drawn much more closely. It is quite possible that many an edifice in London occupies an area sufficiently great to cover the holes that would be made by all the posts that might be driven to mark the precise sites of the North Pole on the earth not only for the the last five or ten thousand years, but probably for periods much more ancient still. It is very likely that the North Pole at the time of the glacial epoch was practically indistinguishable from the North Pole now: in fact, the constancy, or sensible constancy I should, perhaps, rather say, of the situation of this most critical point in our globe is one of the most astonishing facts in terrestrial physics.

Let us, then, assume this broad general fact of the permanency in the position of the North Pole, and deduce the obvious consequences it implies with regard to the earth's movement. At this point we find the convenience of the time-honored illustration in our geography books

which likens the earth to an orange. Let us thrust a knitting needle through the orange along its shortest diameter to represent the axis about which the earth rotates. Not only does the earth perform one revolution about this axis in the space of each sidereal day, but the axis itself has a movement. If the earth's axis always remained fixed, or never had any motion except in a direction parallel to itself, then the point to which it was directed on the sky would never change. We have however seen that the pole in the sky is incessantly altering its position; we are therefore taught that the direction of the earth's axis of rotation is constantly changing. To simulate the movement by the orange and knitting needle, we must imagine the orange to rotate around its axis once in that period of twenty-three hours and fifty six minutes which is well known as the length of the sidereal day; while at the same time the knitting needle, itself bearing, of course, the orange with it, performs a conical movement with such extreme slowness that not less than twenty five thousand years is occupied in making the circuit. The movement, as has often been pointed out, is like that of a peg top which rotates rapidly on its axis while at the same time the axis itself has a slow revolving motion. Thus the phenomena which are presented in the rotation of the earth demonstrate that the axis about which the earth rotates occupies what is, at all events, approximately a fixed position in the earth, though not a fixed position in space. We can hardly be surprised at this result; it merely implies that the earth acts like a rigid body on the whole, and does not permit the axis about which it is turning to change its position.

It will now be easily understood how it comes to pass that the position of the North Pole upon the earth has not appreciably changed in the course of thousands of years. The axis around which the earth rotates has retained a permanent position relative to the earth itself; it has however continuously changed, it is at this moment changing, and it will continue to change with regard to its direction in space. So far our knowledge extended up to within the last few years, but in these modern days a closer inquiry has been made into this, as into as many other physical subjects, and the result has been to disclose the important fact that, though the phenomena as just described are very nearly true, they must receive a certain minute qualification. Complete examination of this subject is desirable, not only on account of its natural importance, but also because it illustrates the refinements of which modern astronomical processes are susceptible. I have stated the broad general fact that the position of the terrestrial pole undergoes no large or considerable fluctuation. But while we admit that no large fluctuation is possible, it is yet very proper to consider whether there may not be a small fluctuation. It is certain that the position of the pole as it would be marked by a post driven into the earth to-day can not differ by a mile from the position in which the same point would be marked last year or next year. But does it differ at all? Is it abso-

lutely exactly the same? Would there be a difference, not indeed of miles but of yards or of feet between the precise position of the pole on the earth determined at successive intervals of time? Would it be the same if we carried out our comparisons, not merely between one year and another, but day after day, week after week, month after month? No doubt the more obvious phenomena proclaim in the most unmistakable manner that the position of the pole is substantially invariable. If therefore there be any fluctuations in its position, those could only be disclosed by careful scrutiny of minute phenomena which were too delicate to be detected in the coarser methods of observation. There is indeed a certain presumption in favor of the notion that absolute constancy in the position of the pole need not be expected. Almost every statement of astronomical doctrine requires its qualification, and it would seem indeed unlikely that when sufficient refinement was introduced into the measurements the position of the pole in the earth should appear to be absolutely unalterable. Until a very recent period the evidence on the subject was almost altogether negative; it was no doubt recognized that there might be some fluctuations in the position of the pole, but it was known that they would only be extremely small, and it was believed that in all probability those fluctuations must be comprised within those slender limits which are too much affected by inevitable errors of observation to afford any reliable result. Perseverance in this interesting inquiry has been at last rewarded; and as in so many similar cases we are indebted to the labors of many independent workers for the recent extension of our knowledge. We are, however, at present most interested by the labors of Mr. Chandler, a distinguished American astronomer, who has made an exhaustive examination into the subject. The result has been to afford a conclusive proof that the terrestrial pole does undergo movement. Mr. Chandler has been so successful as to have determined the law of those polar movements, and he has found that when they are taken into consideration, an important improvement in certain delicate astronomical inquiries is the result. These valuable investigations merit, in the highest degree, the attention, not only of those who are specially devoted to astronomical and mathematical researches, but of that large and ever-increasing class who are anxious for general knowledge with regard to the physical phenomena of our globe.

At first sight it might seem difficult indeed to conduct the investigation of this question. Here is a point on the earth's surface, this wonderful North Pole, which, so far as we certainly know, has never yet been approached to within 400 miles, and yet we are so solicitous about the position of this pole and about its movement that we demand a knowledge of its whereabouts with an accuracy which at first appears wholly unattainable. It sounds almost incredible when we are told that a shift in the position of the North Pole to the extent of 20 yards, or even 20 feet, is appreciable, notwithstanding that we have never

been able to get nearer to it than from one end of England to the other. Indeed, as a matter of fact, our knowledge of the movements of the pole are derived from observations made not alone hundreds but even many thousands of miles distant. It is in such observations as those at Greenwich or Berlin, Pulkowa or Washington, that the determinations have been made by which changes in the position of the pole can be ascertained with a delicacy and precision for which those would hardly be prepared who were not aware of the refinement of modern astronomical methods. I do not however imply that the observations conducting to the discoveries now about to be considered have been exclusively obtained at the observatories I have named. There are a large number of similar institutions over the globe which have been made to bear their testimony. Tens of thousands of different observations have been brought together, and by discussing them it has been found possible to remove a large part of the errors by which such work is necessarily affected, and to elicit from the vast mass those grains of truth which could not have been discovered had it not been for the enormous amount of material that was available. Mr. Chandler has discussed these matters in a remarkable series of papers, and it will be necessary for me now to enter into some little detail, both as regards the kind of observations that have been made, and the results to which astronomers have been thereby conducted.

Greenwich Observatory lies more than 2,000 miles from the North Pole, and yet if the pole were to shift by as much as the width of Regent street, the fact that it had done so would be quite perceptible at Greenwich. Let me endeavor to explain how such a measurement could be achieved. In finding the latitude at any locality we desire, of course, to know the distance between the locality and the equator, expressed in angular magnitude. But though this is distinctly the definition of latitude, it does not at once convey the idea as to how this element can be ascertained. How for instance would an astronomer at Greenwich be able to learn the angular distance of the observatory from the equator? The equator is not marked on the sky, and it is obvious that the observer must employ a somewhat indirect process to ascertain what he wants. Here, again, we have to invoke the aid of that celestial pole to which I have so often referred. Think of that point on the sky which is the common center of the circles exhibited on Prof. Barnard's photograph. That point is not indeed marked by any special star, but it is completely defined by the circumstance that it is the center of the track performed by the circumpolar stars. We thus obtain a clear idea of this definite point in the sky, and the horizon is a perfectly definite line, at all events from any station where the sea is visible. It is not difficult to imagine that by suitable measurements we can ascertain the altitude of this point in the heavens above the horizon. That altitude is the latitude of the place; it is, in fact, the very angle which lies between the locality on the earth and

the equator. It is quite true that as the pole is implied by these circles rather than directly marked by them, the measurement of the altitude can not be effected quite directly. The actual process is to take the Pole-star, or some one of the other circumpolar stars, and to measure the greatest height to which it ascends above the horizon, and the lowest altitude to which it declines about twelve hours later. The former of these is as much above the pole as the latter is below it, so between them we are able to ascertain the altitude of the pole with a high degree of accuracy. It is true that in a fixed observatory such as Greenwich there is no visible sea horizon, and even if there were it would not provide so excellent a method as is offered by the equivalent process of first observing the star directly and then observing its reflection from a dish of mercury. In this way the altitude of the star above the horizon is determined with the utmost precision.

The practical astronomer will however remember that of course he has to attend to the effects of atmospheric refraction, which invariably shows a star higher up than it ought to be. This can be allowed for, and in this way the latitude of the observatory is ascertained with all needful accuracy. When the highest degree of precision is sought for, and it is only observations with a very high degree of precision which are available for our present purpose, a considerable number of stars have to be employed, and very many observations have to be taken at different seasons of the year so as to eliminate, as far as possible, all sources of casual error. When, however, due attention has been paid to those precautions which the experience of astronomers suggests, the result that is obtained is characterized by extraordinary precision. How great that precision may be I must endeavor to explan. The latitude of every important observatory is obtained from a large number of observations, and it would be unlikely that it was more than one or two-tenths of a second different from the actual mean value. Now a tenth of a second on the surface of the earth corresponds to a distance of about 10 feet, and this means that the latitude of the observatory, or, as we must now speak very precisely, the latitude of the center of the meridian circle in the observatory, is known to a degree of precision represented by a few paces. It will thus be seen that with the accuracy attainable in our modern observations, it would often be an appreciable blunder to mistake the latitude of one wall of the observatory for that of the opposite wall; in other words, we know accurately to within the tenth of a second, or within not much more than the tenth of a second, the distance from the center of the transit circle at Greenwich, down to the earth's equator. But, of course, the distance from the pole to the equator is 90°, and this being so it follows that the distance from the north pole of the earth to the center of the transit circle at Greenwich Observatory has been accurately ascertained to within one or two-tenths of a second. If any change took place in the distance between the pole and the meridian circle at Greenwich, then it must be

manifested by the changes of latitude. We shall now be able to understand how any movement of the pole, or rather of the position which it occupies in the earth, would be indicated at Greenwich. Suppose, for instance, that the pole actually advanced towards Great Britain, and that it moved to a distance of, let us say, 30 feet, the effect of this would be to produce a diminution of the distance between the pole and Greenwich, that is to say, there must be an increase in the distance from Greenwich to the equator. This would correspond to a change in the latitude of Greenwich; that latitude would diminish by three-tenths of a second, which is a magnitude quite large enough to be recognizable by the observations I have already indicated as proper for the determination of latitude. A shift of the pole to a distance of 60 feet would be a conspicuous alteration announced in every observatory in Europe provided with instruments of good modern construction.

Until the last few years there was not much reason to think that the pole exhibited any unequivocal indications of movement. No doubt, displacements resembling those which have now been definitely ascertained have existed for many years, but they were too small to produce any appreciable effect, except with instruments of a more refined description than those with which the earlier observatories were equipped. It was obvious that the pole did not make movements of anything like a hundred yards in extent; had it done so the resulting variations in latitude would have been conspicuous enough to have obtained notice many years ago. The actual movements which the pole does make are of that small character which require very minute discussion of the observations to establish them beyond reach of cavil. There is however one striking method of confirming such observations as have been made which leaves no doubt of the accuracy of the results to which they point. Suppose, for instance, that the great observatories in Europe indicate at a certain time that their latitudes have all increased; this necessarily implies that the equator has receded from them, and that, therefore, the North Pole has approached Europe. If however the North Pole has approached Europe it must have retreated from those regions on the opposite side of the world—say, for instance, the Sandwich Islands. Observations in the Sandwich Islands should therefore indicate, if our reasoning has been correct, that the pole has retreated from them, and that the equator has therefore advanced in such a way that the latitudes of localities in the Sandwich Islands have diminished. The various observations which have been brought together by the diligence of Mr. Chandler, including those which he has himself made with an ingenious apparatus of his own design, have been submitted to this test, and they have borne it well. The result has been that it is now possible to follow the movements of the pole with a considerable degree of completeness. Prof. Chandler has tracked the pole month after month, year after year, through a period of more than a century of exact observations, and he has succeeded in determining

the movements which this point undergoes. Let me here endeavor to describe the result at which he has arrived.

In that palæocrystic ocean which Arctic travellers have described, where the masses of ice lie heaped together in the wildest confusion, lies this point which is the object of so much speculation. Let us think of this tract, or a portion of it, to be leveled to a plain, and at a particular center let a circle be drawn, the radius of which is about 30 feet; it is in the circumference of this circle that the pole of the earth is constantly to be found. In fact, if at different times, month after month and year after year, the position of the pole was ascertained as the extremity of that tube from which an eye placed at the center of the earth would be able to see the pole of the heavens, and if the successive positions of this pole were marked by pegs driven into the ground, then the several positions in which the pole would be found must necessarily trace out the circumference of the circle that has been thus described. The period in which each revolution of the pole around the circle takes place is about four hundred and twenty-seven days; the result therefore of these investigations shows, when the observations are accurate, that the North Pole of the earth is not, as has been so long supposed, a fixed point, but that it revolves around in the earth, accomplishing each revolution in about two months more than the period that the earth requires for the performance of each revolution around the sun.

The discovery of the movement of the pole which I have here described must be regarded as a noteworthy achievement in astronomy, nor is the result to which it leads solely of interest in consequence of the lesson it teaches us with regard to the circumstances of the earth's rotation. It has a higher utility, which the practical astronomer will not be slow to appreciate, and of which he has, indeed, already experienced the benefit. There are several astronomical investigations in which the latitude of the observatory enters as a significant element. Latitude is, in fact, at every moment employed as an important factor in many astronomical determinations. To take one of the most simple cases, suppose that we are finding the place of a planet in the observatory. We deduce its position by measuring its zenith distance, and then to obtain the declination the latitude of the observatory has, of course, to be considered. Now astronomers have hitherto been in the habit of accepting the determination of their latitude which had been established by a protracted series of observations, and treating it as if it were a constant. This method will be no longer admissible when astronomical work of the highest class is demanded. No doubt, from the sailor's point of view, an alteration in latitude which at most amounts to a shift of 60 feet—not a quarter, perhaps, of the length of his vessel—is immaterial. But in the more refined parts of astronomical work these discoveries can no longer be overlooked; indeed, Mr. Chandler has shown that many discrepancies by which astronomers had been

baffled can be removed when note is taken of the circumstance that the latitude of the observatory is in an incessant condition of transformation in accordance with the law which his labors have expounded. It will ere long be necessary in every observatory where important work is being done to obtain for every day the correction to the mean value of the latitude, in order to obtain the value appropriate for that day.

There are also other grounds of a somewhat profounder character on which the discoveries now made are eminently instructive. Those who are interested in the physics of our globe often discuss the question as to whether the internal heat, which the earth certainly possesses, is sufficiently intense to render the deep-seated portions of our globe more or less fluid. On the other hand, the effects of pressure, especially of such pressures as are experienced in the depths hundreds and thousands of miles below the surface, must go far to consolidate the materials to form what must be sensibly a rigid body. The question, therefore, arises: Is the earth to be regarded as a rigid mass, or is it not? The phenomena of the tides had already to some extent afforded information on this subject, and now Mr. Chandler's investigation adds much further light, for it is certain from his result that the earth can not be a rigid body. It is quite true that, even though the earth were rigid, the pole might go round in a circle and that circle might have a 30-feet radius, but in such a case the period would be only about three-quarters of the four hundred and twenty-seven days which he has found. In the interest, therefore, of the theoretical astronomer, as well as on the other grounds which I have set forth, Mr. Chandler's investigations must be regarded as a most important contribution to modern astronomy.

THE GREAT LUNAR CRATER TYCHO.*

By A. C. Ranyard.

The late Prebendary Webb used to speak of Tycho as the metropolitan crater of the moon. Though by no means the largest of the lunar craters, it is one of the most striking features of the lunar landscape, especially when the moon is near to the full, and the shadows of the mountains have all disappeared. The crater of Tycho is then seen as a conspicuously white spot, from which radiate in all directions a great number of whitish rays that extend over more than a third of the visible hemisphere of the moon, indicating that the crater has been the center of a colossal disturbance which seems to have shattered the lunar crust in all directions. We have, as far as I am aware, no evidence in the terrestrial geologic record that a corresponding cataclysm has ever similarly shattered the earth's crust; but our terrestrial volcanoes are puny things compared with the giant craters of our smaller companion planet.

As might be expected, the strange phenomena presented in so unparalleled a degree by Tycho have been a fruitful stimulus to speculation as to the origin of the lunar craters and the radiating systems of rays with which many of the moon's craters are evidently intimately connected. Many able men have doubted whether there is any true analogy between terrestrial volcanoes and the gigantic lunar ring mountains and circular depressions which we ordinarily speak of as craters. The ring of Tycho is 54 miles in diameter, and the great crater Clavius, which lies to the south of it, is more than 140 miles in diameter; but Clavius is by no means the largest of the lunar craters. If the lunar Apennines and the other mountains forming a broken ring round the Mare Imbrium are the remnants of a crater, it must have had a diameter of over 600 miles, while the largest terrestrial craters are not more than 15 or 16 miles in diameter.† Vesuvius and the

*From *Knowledge,* August, 1893; vol. XVI, pp. 149–153.

†According to Mr. G. K. Gilbert, in a paper published in the *Bulletin of the Philosophical Society of Washington,* vol. XII, p. 247, (1) the old crater containing Lake Bombon, Isle of Luzon, is mapped (Reclus) as 16 by 14 miles in extent; (2) the crater of Asosan, Isle of Kiushiu, Japan, is 15 miles across (Milne); (3) Scrope mentions a circular crateriform lake, about 15 miles in diameter, in Northern Kam-

Monte Summa would appear as insignificant little hills if they were dropped into the center of the crater of Tycho, whose ring wall towers to a height of 17,000 feet above the plain it incloses.

Robert Hooke compared the lunar craters to the cup-shaped pits formed on the surface of boiling mud by escaping vapor, and the idea has been a fascinating one to many minds since his day, though it needs but little consideration to recognize that bubbles or blisters formed in a plastic material on a scale corresponding with that of the lunar craters would rapidly sink down and be obliterated.

Mr. S. E. Peal has ingeniously advocated a theory which seems to me almost equally untenable. He assumes that the lunar surface consists entirely of ice, and that the craters and pit-like depressions are due to the action of hot springs which have not flowed continuously, but that water has from time to time issued from vents in the soil, and has melted the ice above the vent. The water is then supposed to have flowed back to the warm interior of the moon, taking with it a part of the surface ice that has been melted, and by a series of such ebbs and flows Mr. Peal conceives the terraced walls of the lunar craters to have been built up above the level of surrounding plains. Putting on one side the difficulty of conceiving of nearly perpendicular ice cliffs of 17,000 to 20,000 feet high, standing for ages without flowing down as glaciers to the plains at their feet, we have to account for the fact that the lunar plains and the floors of the deeper lunar craters are generally of a much darker tint than the higher ground upon the moon, while if the whole of the lunar surface were composed of ice and snow there would be no reason for such a difference of tint, unless, as Mr. Peal suggests, the lunar plains are surfaces of virgin ice while the mountains are formed of snow. But virgin ice would reflect the light of the sun specularly, and in the equatorial and tropical parts of the moon from which the sun's rays could be specularly reflected to us there are no traces of such specular reflection. The theory also fails to account for the small craters frequently found on the rims of large craters and on the sloping sides of mountains. Such small craters are far above the assumed rock surface of the moon, and warm water issuing from them would flow down the sides of the mountains leaving marked traces of its flow. The meteoric theory of the formation of lunar craters has also had many advocates. It is alleged that if a pebble be dropped into mud the scar produced has a raised rim and a central hill, which resembles a lunar crater. Even Mr. Proctor had an inclination for this theory. At page 346 of his book on the moon he says: "So far as the smaller craters are concerned, there is nothing incredible in the suppo-

schatka ("Volcanoes," second edition, London, 1862, p. 457); (4) an imperfect crater cirque on Mauritius, mentioned by Charles Darwin, is mapped (Admiralty) as about 15 by 16 miles in extent; (5) the crater walls surrounding Lake Bolesna, Italy, are mapped as 11 by 9 miles in extent; (6) the crater containing Lake Maninju, Sumatra, is mapped (Reclus) as 15 by 7 miles in extent.

sition that they were due to meteoric rain falling when the moon was in a plastic condition. Indeed, it is somewhat remarkable how strikingly certain parts of the moon resemble a surface which has been rained upon, while sufficiently plastic to receive the impressions, but not too soft to retain them. Nor is it any valid objection to this supposition, that the rings left by meteoric downfall would only be circular when the falling matter chanced to strike the moon's surface squarely, for it is far more probable that even when the surface was struck obliquely, and the opening first formed by the meteoric mass or cloud of bodies was therefore markedly elliptic, the plastic surface would close in round the place of impact until the impression actually formed had assumed a nearly circular shape." After inviting attention to the lunar photographs published with his book, Mr. Proctor continues: "It will be seen that the multitudinous craters near the southern part of the moon are strongly suggestive of the kind of process I have referred to, and that, in fact, if one judged solely by appearances one would be disposed to adopt somewhat confidently the theory that the moon had had her present surface contour chiefly formed by meteoric downfalls during the period of her existence when she was plastic to impressions from without. I am however sensible that the great craters, under close telescopic scrutiny, by no means correspond in appearance to what we should expect if they were formed by the downfall of great masses from without. The regular, and we may almost say battlemented, aspect of some of these craters, the level floor, and the central peaks so commonly recognized, seem altogether different from what we should expect if a mass fell from outer space upon the moon's surface. It is indeed just possible that under the tremendous heat generated by the downfall, a vast circular region of the moon's surface would be rendered liquid, and that in rapidly solidifying while still traversed by the ring waves resulting from the downfall, something like the present condition would result."

More recently the meteoric theory of the formation of lunar craters has been taken up and considerably elaborated by an American, Mr. G. K. Gilbert, who has made the theory the subject of an address delivered when retiring from the presidency of the Washington Philosophical Society on December 10, 1892. Recognizing the difficulty alluded to by Mr. Proctor, viz, that most of the lunar craters are circular, while if the meteoric bodies came from outer space many of them ought to strike the moon's surface very obliquely and produce elliptic rings, Mr. Gilbert made a series of experiments in the laboratory and found that when projectiles were thrown obliquely against a target of plastic materials a crater-shaped hole of elliptic contour was formed. In order to obviate this objection to the theory he assumes that the bombarding masses which gave rise to the lunar craters did not come from outer space, but were originally parts of a ring about the earth similar to the ring which encircles the planet Saturn. From this ring he supposes

that the moon was gradually formed, the small bodies constituting the ring having first coalesced into a large number of moonlets which finally all united into a single sphere. According to this hypothesis the lunar craters are the scars produced by the collision of the moonlets which last surrendered their individuality, and according to Mr. Gilbert and a mathematical friend who aided him in the investigation, 58 per cent of the moonlets would, under the circumstances imagined, strike the surface of the moon, making an angle of less than 20° with the vertical, while 70 per cent would strike at an angle of less than 30°, and 80 per cent at an angle of less than 40°. From laboratory experiments Mr. Gilbert found that the ellipticity of the scars on his plastic target increased slowly up to an incidence of 40° to the vertical, and that beyond that incidence the resulting scars showed considerable ellipticity. He assumes that, owing to the flat character of the Saturnian ring about the earth, the moonlets must have approached the moon approximately in the plane of its equator, but the fact is not attested by the grouping of the craters in a medial zone. Mr. Gilbert therefore assumes that the axis of the moon's rotation has shifted under the successive impulses of the bombardment, and that the moon's equator has occupied successively all parts of its surface. He assumes that the velocity of impact due to the moon's gravity would be sufficient to melt the rocks of the lunar surface, and that they would during a short period behave as if they were composed of plastic material, but would become hardened before the crater could subside.

The theory does not at all commend itself to my mind. M. Roche, of Montpelier, showed that a ring about a planet would break up if it extended beyond a distance of 2 11 25ths the radius from the center of the planet, and if the density of the planet increased towards its center the maximum limit to which a ring could extend would be still further contracted. A moon formed just outside such a ring would have an ellipticity greater than that of an ordinary hen's egg; and as tidal action carried the moon away from its primary it would gradually approximate to a spherical form. One can hardly conceive that such a change of shape could take place without obliterating scars on its surface; but there is another objection to the theory, which, to my mind, is even more conclusive. There are upon the moon many lines or strings of small craterlets which fall very evidently into line with one another. If we are forced to treat them as scars upon a target, we must regard their allineation as the result of mere chance distribution; but the number of such strings precludes any such assumption; there must therefore be a physical reason for the allineation, and the most obvious assumption seems to be that the craterlets mark out a line of weakness in the crust of the moon and lie along a volcanic fissure or lunar fault.

There is ever gradation in size and in type from the small craterlets or cup shaped depressions up to the gigantic walled rings, and any

theory which professes to account for craterlets must account for the types of crater into which they gradually merge. We therefore seem driven back to the volcanic hypothesis, and have to explain why upon the moon, which is so much smaller than the earth, the volcanic outbreaks have been on so colossal a scale. We are not even in a position to say that the moon is made of similar materials to the earth—indeed, we know that its average density is considerably less, the earth being about 5·66 times as heavy as a similar globe of water, while the moon is only about 3·39 times as dense as water, or, according to Dr. Gill's recent determination, about 1 per cent less. We must not however conclude from this difference that the moon is made of different materials from the earth, for we know too little as to the behavior of solids under the enormous pressures that they must be subjected to at even a few miles beneath the earth's surface. The average density of the rocks of which the earth's surface is composed is only about two and a half times that of water, but it does not follow that the central parts of the earth are composed of different and heavier material. The great rigidity of the earth under the tidal strains imposed upon it by the sun and moon points to the conclusion that the solid materials of which the earth is built up are rendered rigid by compression, and that the idea of a fluid interior must be abandoned. Mr. George F. Becker, of the U. S. Geological Survey, has recently pointed out that the slags, into which most of the stratified rocks of the earth's surface would be reduced by melting, increase in bulk on fusion, and are not like iron and water, which expand on solidifying: consequently, he argues that any crust which formed on the surface of a molten sphere of slag would speedily break up by its own weight and sink, and that the process would go on until the whole mass had been reduced in temperature by such upheavals to near the melting point of the slag. But if the liquid slag, or other materials of which the earth is composed, were capable of being reduced by the pressure of the superincumbent mass to the solid condition, such upheavals would not take place, and under such circumstances it is possible that the heat of the earth may go on increasing to its center.

If below the surface of the earth large masses of highly heated rock are kept solid by the enormous pressure of overlying rocks, earth movements, caused by the cooling and contraction which crumple up the stratified rocks of the surface and give rise to the upheaving of mountain chains, may occasionally take off some of the weight from the rocks beneath, causing the highly heated rocks to run off into the liquid state again and find their way to the surface, causing the phenomena we know as volcanic action.

If we adopt this theory of volcanic action, and assume that the moon is made of similar materials to the earth, we shall—with lunar gravity only equal to one-sixth of terrestrial gravity—need to pass to a depth six times as great upon the moon in order to obtain the pressure neces-

sary to solidify liquid lava at a temperature equivalent to that at which it is solidified beneath the earth's surface, and any change of pressure that releases a stratum of rock from the solid to the liquid state would upon the moon release a stratum approximately six times as thick, other conditions being similar, and would presumably give rise to lava flows on a gigantic scale compared with terrestrial evolutions. Added to these considerations, we must remember that under the feeble action of lunar gravity crater rings and cliffs may be built up of similar material much more steeply upon the moon than at the earth's surface.

There are many formations upon the moon which do not take the form of crater rings. The Riphæan Mountains as shown in a photograph taken by the Brothers Henry in May, 1890, is a very good instance to cite. I should like to draw special attention to a curious straight black streak between the crater's Birt and Thebit. It is spoken of by Webb as a wall, but it rather seems to be a narrow valley or fault. It is shown on several of the photographs taken by the Brothers Henry. I would also draw the reader's attention to three dark spots on the floor of the crater Alphonsus, which are shown in all good photographs, as well as the curious marking, like a capital G, near to the centre of the Mare Nubian.

THE EARLY TEMPLE AND PYRAMID BUILDERS.*

By J. Norman Lockyer.

I have in previous articles discussed the orientation of many temples in various parts of Egypt. It will have been seen that it has been possible to divide them into solar and stellar temples, and that in the case of the former both solstices and equinoxes have been in question.

I have also referred to the very considerable literature which already existsas to the pyramids, and shown how the most carefully constructed among them are invariably oriented truly to the four cardinal points, and further that it is possible that some parts of their structures might have served some astronomical purpose, since astronomical methods must certainly have been employed in their construction.

It has also been suggested that the fundamental difference between solstitial and equinoctial worships, indicated by the solstitial temples and the pyramids, required nothing less than a difference of race to explain it. I propose now to inquire if there be any considerations which can be utilized to continue the discussion of the question thus raised on purely astronomical grounds. It is obvious that, if sufficient tradition exists to permit us to associate the various structures which have been studied astronomically with definite periods of Egyptian history, a study of the larger outlines of that history will enable us to determine whether or not the critical changes in dynasties and rulers were or were not associated with critical changes in astronomical ideas as revealed by changes in temple worship. If there be no connection, the changes may have been due to a change of idea only, and the suggestion of a distinction of race falls to the ground.

In a region of inquiry where the facts are so few and difficult to recognize among a mass of myths and traditions, to say nothing of contradictory assertions by different authors, the more closely we adhere to a rigidly scientific method of inquiry the better. I propose to show therefore that there is one working hypothesis which seems to include a great many of the facts, and I hope to give the hypothesis and the facts in such a way that if there be anything inaccurately or incompletely

* From *Nature*, May 18, 1893; vol. XLVIII, pp. 55–58.

stated it will be easy at once to change the front of the inquiry and proceed along the new line indicated.

I may begin by remarking that it is fundamental for the hypothesis that the temples of On or Heliopolis, as stated by Maspero and other high authorities, existed before the times of Mini (Menes) and the pyramid-builders, whatever may have been the date of the original foundation of Thebes.

Before Mini, according to Maspero, "On et les villes du Nord avaient eu la part principale dans le développement de la civilisation Égyptienne. Les prieres et les hymnes, qui formèrent plus tard le noyau des livres sacrés, avaient été rédigés sà On." *

The working hypothesis is as follows:

(1) The first civilization as yet glimpsed in Egypt, represented by On or Heliopolis, was a civilization with a solstitial solar worship associated with the rise of the Nile. A northern star was also worshiped.

(2) Memphis (possibly also Sais, Bubastis, Tanis, and other cities with east and west walls) and the pyramids were built by an invading race from a land where the worship was equinoctial. A star rising in the east was worshiped at the equinox.

(3) The blank in Egyptian history between the sixth and eleventh dynasties was associated with conflicts between these races, which were ended by the victory of the representatives of the old worship of On. After them pyramid building ceased and solstitial worship was resuscitated; Memphis takes second place, and Thebes, a southern On, so far as solstitial solar worship is concerned, comes upon the scene as the seat of the twelfth dynasty.

(4) The subsequent historical events were largely due to conflicts with intruding races. The intruders established themselves in cities with east and west walls, and were on each occasion driven out by solstitial solar worshipers, who founded dynasties (eighteenth and twenty-fifth) at Thebes.

I.—ON.

I have taken another occasion of remarking how the various worships at Thebes were reflected in the orientation of the temenos walls. The so-called "symmetrophobia" of the Egyptians was full of meaning, which in this case, at all events, is no longer hidden. If we note this reflection, as we can over and over again, where both temples and walls still stand, it is fair to assume that where the walls alone remain the temples which they once inclosed, long since destroyed, had the same relation. These considerations, alas, have to be appealed to in the case of Heliopolis, to say so far nothing of Abydos and Memphis.

At Heliopolis the so-called "symmetrophobia," as indicated by the trend of the mounds given in Lepsius's plan, is so strong that, in spite of the fact that only one obelisk of one temple remains, it is easy to

* "Histoire ancienne," p. 41.

show that both solstitial solar worship and star worship were carried on, if walls had the same relation to the included temples at On as they had at Thebes.

The solar temple at On has entirely disappeared. As may be gathered from the remains of the mounds, it lay in the line of the solstices. As the gods included Rā, Atmu, and Osiris, probably like the temple of Amen Rā at Thebes, there were two temples back to back. At Thebes the temples were directed northwest to southeast, at On southwest to northeast.

My observations of the orientation of the obelisk show that the temple of which it formed a part may have possibly been the first of the series which includes the temple of Mut at Thebes, and other temples there and at Abydos; that is the worship of Set was in question, to speak generically. Now, according to Maspero,* Sit or Set formed one of the divine dynasties, being associated with the sun and air gods at On, i. e., with Rā, Atmu, Osiris, Horus, and Shou.

At Abydos, as also can be determined by the orientation of the walls, one of the oldest temples was probably a solstitial one. The stellar temples, sacred to Set, were built much later than the solar temple.

Like On, Abydos was a sacred city.† "C'est comme ville sainte qu'elle était universellement connue. Ses sanctuaires etaient célèbres, son dieu Osiris vénéré, ses fêtes suivies par toute l'Égypte; les gens riches des autres nomes tenaient à honneur de se faire dresser une stèle dans son temple."‡

If it be found that the references to "ancestors" and "divine ancestors" occur after the eleventh dynasty, the race represented by On may be referred to and it may be that so often referred to as the Hor-shesu.

Only one star temple, as I have said, is still represented at On; those at Abydos are known to be late. The term, then, of Sun-worshippers was highly distinctive, and there is reason to believe that the stellar observations were connected with the solar worship.

II.—(*a*) THE EAST AND WEST WALLS AND PYRAMID BUILDERS.

On the hypothesis these came from a country where the worship was equinoctial.

We are justified from what is known regarding the rise of the Nile as dominating and defining the commencement of the Egyptian year that other ancient peoples placed under like conditions would act in the same way.

Now what the Nile was to Egypt the valleys of the Tigris and the Euphrates were to the early Chaldean empire. Like the Nile, these

* *Op. cit.*, p. 33.

† Maspero, *op. cit.*, p. 21.

‡ It is important to inquire if this took place after the advent of the eleventh dynasty.

valleys were subject to annual inundations, and their fertility depended, as in Egypt, upon the manner in which the irrigation was looked after. But unlike the Nile, the commencement of the inundation of these rivers took place near the vernal equinox; hence the year, we may assume, began then, and, reasoning by analogy, the worship in all probability was equinoctial.

A people entering Egypt from this region, then, would satisfy one condition of the problem, but is there any evidence that this people built their solar temples and temple walls east and west, and that they also built pyramids?

There is ample evidence, although, alas, the structures in Chaldæa, being generally built in brick and not in stone, no longer remain, as do those erected in Egypt. Still, in spite of the absence of the possibility of a comparative study, research has shown that in the whole region to the northeast of Egypt the temenos walls of temples and the walls of towns run east and west; and, though at present actual dates can not be given, a high antiquity is suggested in the case of some of them. Further, the temples which remain in that region where stone was procurable, as at Palmyra, Baalbec, Jerusalem, all lie east and west. But more than this, it is well known that from the very earliest times pyramidal structures, called ziggurats, some 150 feet high, were erected in each important city. These were really observatories; they were pyramids built in steps, as clearly shown from pictures found on contemporary tablets; and one with seven steps and of great antiquity, it is known, was restored by Nebuchadnezzar, about 600 B. C., at Babylon. A second condition of the hypothesis is therefore satisfied.

But did this equinox-worshiping, pyramid-building race live at anything like the time required? Prof. Sayce showed in the Hibbert lectures, which were delivered in the year 1887, that recent finds have established the existence of a King Sargon I, at Agade in Chaldea, 3800 B. C. Hence it seems that a third condition of the hypothesis is satisfied by this recent discovery. There was undoubtedly an equinox-worshiping pyramid-building race existing in Chaldea at the time the Egyptian pyramids are supposed to have been built.

Hommel, in a recent paper on the Babylonian origin of Egyptian culture, shows that the names of the gods corresponded in many cases with the names of deities mentioned in the oldest Egyptian pyramid texts. - - - The names were represented by exactly the same signs in both Babylonian and Egyptian hieroglyphics, - - - the name and signs of Osiris the Babylonian Asari are represented in both countries by an eye. He contends that there had been a direct communication between the two civilizations, and that the Babylonian was the older of the two.

Next let us return to Egypt. We find at Memphis, Sais, Bubastis, and Tanis east and west walls, which at once stamp those cities as differing in origin from On, Abydos, and Thebes, where, as I have

shown, the walls trend either northwest to southeast or northeast to southwest.

For Memphis, Sais, and Tanis, the evidence is afforded by the maps of Lepsius. For Bubastis it depends upon the statement of Naville, that the walls run "nearly from east to west," and with the looseness too often associated with such statements, it is not said whether true or magnetic bearings are indicated.

Associated with these east and west walls there is further evidence of great antiquity. Bubastis, according to Naville,* has afforded traces of the date of Cheops and Chephren, and it is stated by Manetho to have existed as early as the second dynasty.

It is also generally known that the pyramids in Egypt are oriented east and west. Nor is this all. One of the oldest, if not the oldest, pyramid known, is a step pyramid modelled on the ziggurat pattern, the so-called "step pyramid of Sakkarah." The steps are six in number, and vary in height from 38 to 29 feet, their width being about 6 feet. The dimensions are 352 (north and south) × 396 (east and west) × 197 feet. Some authorities think this pyramid was erected in the first dynasty by the fourth king (Nenephes of Manetho, Āta of the tablet of Abydos). The arrangement of chambers in this pyramid is quite special.

The claim to the highest antiquity of the step pyramid is disputed by some in favor of the "false pyramid of Médûm. It also is really a step pyramid 115 feet high, its outline, which conceals some of the steps, shows three stages, 70, 20, and 25 feet high, but in its internal structure it is really a step pyramid of six stages.

This pyramid must, according to Petrie, be attributed to Seneferu; but De Rougé has given evidence to the contrary.† Seneferu was a king of the fourth dynasty.

We have at Dashour the only remaining abnormal pyramid, called the blunted pyramid, for the reason that the inclination changes at about one-third of the height. This pyramid forms one of a group of four, two of stone, and, be it carefully borne in mind, two of brick; their dimensions are 700 × 700 × 326 feet; 620 × 620 × 321 feet; 350 × 350 × 90 feet, and 343 × 343 × 156 feet.

One of these pyramids was formerly supposed to have been built by Seneferu. If any of them had been erected by King Ousertsen III of the twelfth dynasty, as was formerly thought, the hypothesis we are considering would have been invalid.

Only after Seneferu then do we come to the normal Egyptian pyramid, the two largest at Gizeh, built by Cheops and Chephren (fourth dynasty), being, so far as is accurately known, the oldest of the series. (According to Mariette, the date of Mini is 5004 B. C., and the fourth dynasty commenced in 4235 B. C.)

* "Bubastis," preface, p. iv. † Maspero, *op. cit.*, p. 59

Associated with the cities with east and west walls are temples facing due east; fit therefore to receive the rays of the morning sun rising at an equinox.

Associated with these pyramids, carefully oriented east and west, we find on their eastern sides some distance away and on a line passing through their centers at right angles to a meridian line, temples facing due west, the clearest possible indication of equinoctial worship. At sunset at the equinox the sepulchral chamber and the sun were in a line from the adytum. The priest faced a double Osiris.

In the case of the pyramid of Chephren, not only have we (as I hold) such a temple of Osiris, but the Sphinx granite temple was most probably the crypt of a temple of Isis, its relation to the south face of the pyramid being borne in mind. If this were so, Osiris was a name both for the solstitial and equinoctial sun.

Other pyramids were built at Sakkarah during the sixth dynasty, but it is remarkable that such a king as Pepi-Meri-Rā should not have imitated the majestic structures of the fourth dynasty. He is said to have built a pyramid at Sakkarah, but its obscurity is evidence that the pyramid idea was giving way, and it looks as if this dynasty were really on the side of On,* for the authority of Memphis declined and Abydos was preferred, while abroad Sinai was re-conquered and Ethiopia was kept in order.†

The sphinx (oriented true east) must also be ascribed to the earliest pyramid builders; it could not have been built before their intrusion. The Colossi of the plain at Thebes was a subsequent reply of the On solstitial worship to it.

(*b*) THE WORSHIP OF THE BULL BY THE PYRAMID BUILDERS.

There is a subsidiary point in connection with the pyramid builders and equinoctial worship.

The worship of Apis preceded the building of pyramids. Mini is credited by Elian with its introduction,‡ but at any rate Kakau of the second dynasty issued proclamations regarding it,§ and a statue of Hapi was in the temple of Cheops.||

It is stated that the first month of the Chaldæan year was dedicated to the "propitious bull," and that the figure of a bull constantly occurs on the monuments as opening the year. Now the sun *at the vernal equinox* 4500 B. C. was in the constellation Taurus. Biot has shown that the equinox occurred with the sun near the pleiades in 3285 B. C.

* Maspero, *op. cit.*, p. 80.

† Further, it is known that there was some connection between Pepi-Meri-Rā and the eleventh dynasty of Thebes. Maspero, *op. cit.*, p. 91.

‡ Maspero, *op. cit.*, p. 44, note.

§ Maspero, *op. cit.*, p. 46.

|| Maspero, *op. cit.*, p. 64.

We seem driven to the conclusion that the constellation of the bull dates from this time, and that Hapi represented it.*

(*c*) THE ART OF THE PYRAMID BUILDERS.

Another connecting link is found in the diorite statues found in the temple of Chephren, at the pyramids, and at Tell-loh (ancient Sirgulla) by M. de Sarzec in 1881. This last find consisted of some large statues of diorite, and the attitude chosen was that of Chephren himself as represented in the Museum of Gizeh. This indicates equality in the arts and the possession of similar tools in Chaldæa and Egypt about the time in question.

(*d*) THE STAR WORSHIP OF THE PYRAMID BUILDERS.

I have given before the gods of Heliopolis, and have shown that with the exception of Sit none are stellar, and that the temple of Sit is still represented. But we find in pyramid times the list is vastly changed; only the sun gods, Ra, Horus, Osiris, are common to the two. As new divinities we find:†

Isis,	Nephthys,	Serk-t,
Hathor,	Ptah,	Sokhit.

Of these the first two and the last two undoubtedly symbolized stars, and there can be no question that the temple of Isis at the pyramids was built to watch the rising of some of them.‡ Of Isis and Hathor I have already written at length, and I think the stars are now known. The others are more doubtful, but it may be that Ptah = Capella and Serk-t = Antares.

But it is also stated that at Memphis§ [time not given] there were temples dedicated to Soutekh and Baal. Now this is of great importance, for I suppose there is now no question among Egyptologists that the gods Set, Sit. Typhon, Bes, Soutekh, Soutkhou are identical. It is also equally well known that Soutekh was a god of the Canaanites;‖ that the hippopotamus, the emblem of Set and Typhon, was the hieroglyph of the Babylonian god Baal,¶ and Bes is identified with Set in the book of the dead.**

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* Not only the bull; there is evidence in favor of the view that the goddess Serk-t = Antares. If so, the scorpion constellation had also been established and both equinoxes marked by constellations in the time of Cheops.

† Maspero, *op. cit.*, p. 64.

‡ The temple of Saïs, as I have said, had east and west walls, and so had Memphis, according to Lepsius. The form of Isis at Saïs was the goddess Neith, which, according to some authorities, was the precursor of Athene. The temple of Athene at Athens was oriented to the pleiades.

§ Maspero, *op. cit.*, p. 357.

‖ Maspero, *op. cit.*, p, 165.

¶ Pierret, p. 4.

** *Idem*, p. 48.

Jensen, in his *Kosmologie der Babylonier*, p. 16, points out that Bīl was the name for the pole of the equator. If this be the Baal referred to by Pierret, we get the most marvellous coincidence between the Egyptian and Babylonian star worship and suggestion of a common origin among an astronomically minded people.

This suggests that the founders of On and Memphis had a common origin, and the Memphitic intrusion took place after solar solstitial worship had been introduced at On. This worship could not have been brought into Egypt from any other country bordering on Chaldæa, and its ultimate predominance is the origin of the myth of Horus slaying the hippopotamus. Nay, it may be also suggested that the predominance was brought about by men and ideas reaching On from the south, so that the myth had a single celestial and a double terrestrial side.

The Hawk God of Edfû, Harhouditi, had for servants a number of individuals called Masniou or Masnitiou=blacksmiths, just as the Hawk God of the Delta, Harsiisit, has for his entourage the Shosou Horou. Maspero, in a most interesting paper,* has recently called attention to some customs still extant among the castes of blacksmiths in Central Africa which have suggested to him that the followers of the Edfû Horus may have come from that province.

He writes: "C'est du sud de l'Égypte que les forgerons sont remontés vers le nord; leur siège primitif était le sud de l'Égypte, la partie du pays qui a le plus des rapports avec les régions centrales de l'Afrique et leurs habitants."

Then, after stating the present conditions of these workers in equatorial Africa, where they enjoy a high distinction, he concludes:

"Je pense qu'on peut se représenter l'Horus d'Edfou comme étant au début, dans l'une de ses formes, le chef et le dieu d'une tribu d'ouvriers travaillant le métal ou plutôt travaillant le fer. On ne saurait en effet se dissimuler qu'il y a une affinité réelle entre le fer et la personne d'Horus en certains mythes. Horus est la face céleste (horou), le ciel, le firmament, et ce firmament est de toute antiquité, un toit de fer, si bien que le fer en prit le nom de ba-na-pit, métal du ciel, métal dont est formé le ciel: Horus l'aîné, Horus d'Edfou, est donc en réalité un dieu de fer. Il est, de plus, muni de la pique ou de la javeline à point de fer, et les dieux qui lui sont apparentés, Anhouri, Shou, sont de piquiers comme lui, au contraire des dieux du nord de l'Égypte, Ra, Phtah, etc., qui n'ont pas d'armes à l'ordinaire. La légende d'Harhouditi conquerant l'Égypte avec les masniou serait-elle donc l'écho ointain d'un fait qui se serait passé au temps antérieurs a l'histoire? Quelque chose comme l'arrivée des Espagnols au milieu des populations du Nouveau Monde, l'irruption en Égypte de tribus connaissant et employant le fer, ayant parmi elles une caste de forgerons et apportant le culte d'un dieu belliqueux qui aurait été un Horus ou se serait confondu avec l'Horus des premiers Égyptiens pour former Hardouditi. Ces tribus auraient été nécessairement d'origine Africaine et auraient apporté de nouveaux éléments Africains à ceux que renfermait déjà la civilisation

* *L'Anthropologie*, July-August, 1891, No. 4.

du bas Nil. Les forgerons auraient perdu peu à peu leurs privileges pour se fondre au reste de la population: à Edfou seulement et dans les villes où l'on pratiquait le culte de l'Horus d'Edfou, ils auraient conservé un caractère sacré et se seraient transformés en une sorte de domesticité religieuse, les masniou du mythe d'Horus. compagnons et serviteurs du dieu guerrier."*

III.—THE WORK OF THE ELEVENTH AND TWELFTH DYNASTIES.

We have next to consider what happened after the great gap in Egyptian history between the sixth and twelfth dynasties, 3500 B. C.–2851 B. C. (Mariette), from Nitocris to Amenemhat I. We pass to the Middle Empire.

Amenemhat I built no pyramids, he added no embellishments to Memphis, but he took Heliopolis under his care, and now we first hear of Thebes.†

Usertesen I built no pyramids, he added no embellishments to Memphis, but he also took Heliopolis under his care and added obelisks to the temples, one of which remains to this day. Further, he restored the temple of Osiris at Abydos and added to the temple of Amen-Ra at Thebes. †

Surely it is very noteworthy that the first thing the kings of the twelfth dynasty did was to look after the only three temples in Egypt of which traces exist, which I have shown to have been oriented to the solstice. It is right however to remark that there seems to have been a mild recrudescence of pyramid building toward the end of the twelfth dynasty, and immediately preceding the Hyksos period, whether as a precurser of that period or not.

Usertesen's views about his last home have come down to us in a

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* The Horus of Edfou was represented as the chief and god of a tribe working in metal, more especially in iron. There is no doubt that in certain myths there is a connection between the person of Horus and iron. Horus represented the sky, the firmament; in antiquity the sky was thought to be a roof of iron, so much so that the Egyptians called iron the sky metal. Horus usually carried an iron pointed pike or javelin, as do the allied gods Anhouri and Shou, while the gods of the north of Egypt, Ra, Phtah, etc., are unarmed. Is not the legend of Horhouditi conquering Egypt with the help of the masniou (blacksmiths), an echo of an event which occurred in the prehistoric period of Egypt. Comparable to the arrival of the Spaniards in North America, was the invasion into Egypt of tribes knowing and using iron, having among them a special caste of smiths, who brought with them the cult of a warlike god, who they either called Horus or identified with the Horus of the early Egyptian afterwards named Horhouditi. These tribes were of course of African origin, and they brought new African elements to those already contained in the civilization of the lower Nile. The smiths by and by lost their ancient privileges as they were gradually merged in the rest of the population; only at Edfou and in the towns which practiced the cult of the Horus of Edfou did they preserve a sacred character, being transformed into a kind of domestic religious class, i. e., the *masniou* of the myth of Horus, companions and servants of the warlike god.

† Maspero, *op. cit.*, p. 112.

writing by his scribe Miri:* "Mon maître m'envoya en mission pour lui préparer une grande demeure éternelle. Les couloirs et la chambre intérieure étaient en maçonnerie et renouvelaient les merveilles de construction des dieux. Il y eut en elle des colonnes, sculptées, belles comme le ciel, un bassin creusé qui communiquait avec le Nil, des portes, des obélisques, une façade en pierre de Rouou."

There was nothing pyramidal about this idea, but one hundred and fifty years later we find Amenemhat III returning both to the gigantic irrigation works and the pyramid building of the earlier dynasties.

The scene of these labors was the Fayyûm, where, to crown the new work, two ornamental pyramids were built, surmounted by statues, and finally the king himself was buried in a pyramid near the Labyrinth.

IV.—THE WORK OF THE EIGHTEENTH DYNASTY.

The blank in Egyptian history between the twelfth and eighteenth dynasties is known to have been associated with the intrusion of the so-called Hyksos. It is supposed these made their way into Egypt from the countries in and to the west of Mesopotamia. It is known that they settled in the cities with east and west walls. They were finally driven out by Aahmes, the king of solstitial solar Thebes, who began the eighteenth dynasty.

In (*a*) I have shown what happened after the first great break in Egyptian history—a resuscitation of the solstitial worship at On, Abydos, and Thebes.

I have next to show that precisely the same thing happened after the Hyksos period (Dyn. 13 (?) Mariette, 2233 Brugsch; Dyn. 18, 1703 B. C., Marietta) had disturbed history for some five hundred years.

It is known from the papyrus Sellier (G. C. 257) that Aāhmes, the first king of the eighteenth dynasty, who re-established the independence of Egypt, was in reality fighting the priests of Soutekh in favor of the priests of Amen-Rā, the solstitial solar god, a modern representative of Atmu of On.

Amen-Rā, was the successor of Menthu, the successor of Atmu of On. So close was the new worship to the oldest at On, that at the highest point of Theban power the third priest of Amen took the same titles as the Grand Priest of On, "who was the head of the first priesthood in Egypt."† The "Grand Priest of On," who was also called the "Great Observer of Rā and Atmu," had the privilege of entering at all times into the Habenben or Naos. The priest Padouamen, whose mummy was found in 1891, bore these among his other titles.

The assumption of the title was not only to associate the Theban priesthood with their northern confrères, but surely to proclaim that the old On worship was completely restored.

* Maspero, *op. cit.*, p. 113.

† Virey, "New Gizeh Catalogue," p. 263.

V.—THE WORK OF THE TWENTY-FIFTH DYNASTY.

There was another invasion from Syria, which founded the twenty-second dynasty, and again the government is carried on in cities with east and west walls (Sais, Tanis, and Bubastis). The solstitial solar priests of Thebes withdraw to Ethiopia. They return, however, in 700 B. C., drive out the Syrian invaders, and, under Shabaka and Taharga, found a dynasty (the twenty-fifth) at Thebes, and embellish the solstitial solar temples there.

VI.—ANTHROPOLOGICAL EVIDENCE.

It will be seen then that a general survey of Egyptian history does suggest conflict between two races, and this, of course, goes to strengthen the view that the temple building phenomena suggest two different worships, depending upon race distinctions.

We have next to ask if there is any anthropological evidence at our disposal. It so happens that Virchow has directed his attention to this very point.*

Premising that a strong race distinction is recognized between peoples having brachycephalic or short, and dolichocephalic or long, skulls, and that the African races belong to the latter group, I may give the following extract from his paper:

"The craniological type in the ancient empire was different from that in the middle and new. The skulls from the ancient empire are brachycephalic, those from the new and of the present day are either dolichocephalic or mesaticephalic; the difference is therefore at least as great as that between the dolichocephalc skulls of the Frankish graves and the predominantly brachycephalic skulls of the present population of South Germany. I do not deny that we have hitherto had at our disposal only a very limited number of skulls from the ancient empire which have been certainly determined; that therefore the question whether the brachycephalic skull-type deduced from these was the general or at least the predominant one can not yet be answered with certainty, but I may appeal to the fact that the sculptors of the ancient empire made the brachycephalic type the basis of their works of art, too."

It will be seen then that the anthropological as well as the historical evidence "runs on all fours" with the results to be obtained from such a study of the old astronomy as the temples afford us.

* Prof. R. Virchow: "Land und Leute im alten und neuen Aegypten." *Verhandlungen der Geselschafft für Erdkunde zu Berlin,* Band XV, No. 9, pp. 434–436.

VARIABLE STARS.*

By Prof. C. A. Young.

For the most part the stars maintain their places and brightness apparently unchanged; the heavens of to-day are substantially the same as those of Job and Homer. The comparison of a modern star catalogue with that of Hipparchus as preserved by Ptolemy shows that with few and generally slight exceptions the principal stars still hold the same relative positions and the same rank in brightness which they did two thousand years ago. And yet we know that all the time they have been swiftly moving in all directions at rates sometimes exceeding 100 miles a second—some approaching us and some receding. Then, too, they have all been growing old together, some advancing from stellar infancy toward adult vigor, and some descending toward extinction. The apparent permanence is apparent only,—due simply to the fact that the scale of human life and all our terrestrial surroundings is practically infinitesimal as compared with that of the stellar universe. Even the nearest star is so remote that if it were rushing directly toward us with the speed of 100 miles a second it would gain in brightness only about 2½ per cent in a century, an amount barely observable by our best photometers. As to changes due merely to advancing age, a century bears only some such ratio to the lifetime of a star as a single minute to that of an aged man.

But while all this is true there are several hundred stars which are known as "variables," and undergo considerable changes of brightness, sometimes quite rapidly. They form the subject of a most interesting and important chapter in astronomy,—a chapter which may be regarded as opened by Tycho's observations of the marvellous star of 1572, but even yet only begun; in fact, nearly all the systematic work that has been done in this line has been accomplished within the last sixty years.

These "variables" may be roughly classified as follows: First, we have a few stars that seem to be gradually, and more or less steadily, growing brighter or fainter, judging from their present rank as compared with that which they used to hold: *Alpha Geminorum* is a case

* From *The Popular Science News,* Boston, Dec., 1893; vol. XXVII, pp. 177, 178.

in point, being now distinctly fainter than its neighbor, *Beta*, although presumably when Bayer assigned the letters, about three hundred years ago, the reverse was the case. A second class consists of those which oscillate in brightness, but without any apparent regularity, like *Eta Argus*, and *Alpha Orionis*. The third class is made up of the so-called "temporary stars," stars which suddenly shine out and after a few months disappear or become very faint. There have been about a dozen instances of this kind, the last being the "new star in *Auriga*," which appeared in 1892. The fourth class, and by far the most numerous, is made up of those which vary periodically in brightness in a manner which admits of mathematical prediction. Among these periodic stars, at least three sub-classes are to be distinguished: (*a*) Those which at regular intervals brighten up for a comparatively short time and then fall back to their normal condition until the next maximum. These are often referred to as the "*Omicron Ceti* type," because that star usually called *Mira*, or the "wonderful," is the most conspicuous and longest known of all that belong to it. The majority of the periodic stars belong to this sub-class, and generally repeat their changes about once a year, though their periods range all the way from one hundred and ten days to six hundred and ten. (*b*) The second sub-class includes the stars which, like *Beta Lyræ*, are in a continual state of activity; they often present more than one maximum of brightness within a single complete period, which is usually somewhere between five days and sixty. (*c*) Finally, we have the ten stars of the so-called "*Algol* type," which behave in a manner precisely the opposite of that of the stars of the first sub class, *i. e.*, they undergo periodical diminutions or eclipses of their light, remaining for the remainder of the time steadily bright. Their periods are always short, ranging from seven hours to ten days. The type of the class is *Beta Persei*, better known as *Algol*.

The variations of the stars of this class can be very simply explained as merely due to actual eclipses, and the truth of this explanation has been practically established within the last three years by the spectroscopic work of Vogel, at Potsdam. The period of *Algol* is a trifle under sixty-nine hours, and the photographs show that seventeen hours before the obscuration the lines of its spectrum are displaced toward the red by an amount which indicates that it is then receding from us at the rate of about 27 miles a second, while seventeen hours after the obscuration it is found to be approaching at the same rate; in short, the observations prove that the star is moving in an orbit nearly circular, a little more than 2,000,000 miles in diameter, and lying in a plane nearly passing through the observer. Now if the periodical obscuration is really caused by the interposition of an eclipsing body, the bright star must necessarily circulate around the common center of gravity between itself and its dusky attendant in just this sort of way, and the detection of such motion falls little short of a demonstration of

the hypothesis. We may go further: taking into account the fact that the whole "eclipse" lasts for about eight hours, and that the star loses about two-thirds of its light at the time of maximum obscuration (when the brightness remains without change for about twenty minutes), it can be safely inferred that the dark attendant is just about four-fifths the diameter of the bright star and about half as heavy. Also that the distance between the two is about 3,250,000 miles, the diameters of the two bodies being respectively about 1,060,000 and 840,000 miles. Moreover, the combined mass of the two is about two thirds that of the sun, and their density only one-fifth as great, not much exceeding that of cork.

Nor is this all; since the discovery of the variability of the star in 1782, a slight but distinct variation of the period has been observed, of such a character as to set the times of eclipse alternately backward and forward by about two hours and a half in the interval between 1804 and 1869. From this, combined with certain minute irregularities in the "proper motion" of the star, Mr. Chandler two years ago showed that *Algol* and its companion must be moving together in a great orbit, nearly as large as that of the planet Uranus, completing the revolution in a period of about one hundred and thirty years; at least, such a revolution would account for the facts, while no other hypothesis yet proposed will do so. And if this revolution is real, it must be around some neighboring body, so faintly luminous that it has not yet been detected. The story of *Algol* opens up to us a new universe of "dark stars"—bodies invisible, but massive and powerful. Presumably the other stars of the *Algol* class admit of a similar explanation, although as yet they have not been spectroscopically studied, being all of them small and too faint for investigation with the instruments at present available. When the great Yerkes telescope, now nearing completion, is mounted at Lake Geneva it is expected that one of its earliest applications will be to investigations of this sort. It should be added also that certain peculiarities in the light curves of some of these stars seem to indicate that we have not quite reached the bottom of the matter; that in addition to the eclipse, and perhaps caused by it, there are real variations in the light giving power of the star.

As to the other classes of variables, there is no such satisfactory explanation nor any generally received theory. In the case of *Beta Lyræ* and its congeners, we have apparently mechanical and other causes combined—the axial revolution of a star, perhaps, or possibly the whirling of a group of stars, accompanied by tidal changes in the brightness and spectroscopic characteristics of their light, for while the minima of the *Algol* variables are not accompanied by any alteration of the character of the lines in their spectra, it is not so with the other variables; their spectra are almost all of them characterized by bright lines, which become especially brilliant at the time of maximum brightness. *Beta Lyræ* presents conspicuously in its spectrum both

bright and dark lines, due to hydrogen; and these shift back and forth with reference to each other in such a way as apparently to indicate the presence of two or more bodies whirling around each other, one of them giving the ordinary dark-line spectrum and the other the bright-line spectrum of the gas.

The stars of the first and much the most numerous sub-class are nearly all distinctly red and show in their spectra the bright lines of hydrogen, but do not as yet furnish any certain evidence that their periodicity is of a mechanical origin due; that is, to a revolution of some sort. Possibly the explanation proposed by Lockyer may ultimately be verified—that the sudden evolution of light is due to the collision between two swarms of meteors which revolve around their common center of gravity, and brush against each other as they pass their perihelion point. But the periodicity of this class of variables is hardly regular enough to suit this explanation, and the sudden outburst of the bright lines in the spectrum of a star suggests rather some such action, though on a vastly grander scale, as that which causes the sun spots and the solar prominences,—causes operating within the star itself.

As to the "temporary stars" opinion is much divided. On the one hand Lockyer and his numerous followers attribute the phenomena to the collision of swarms of meteors, while on the other Huggins and Vogel are disposed to assimilate them to the solar eruptions. The latest instance of the kind, the "Nova Aurigæ" already alluded to, which appeared in February, 1892, has been most exhaustively studied by a great number of observers. It is agreed on all hands that at first its spectrum was full of bright lines, and dark lines also; and that among these lines those of hydrogen, both bright and dark, were specially conspicuous, just as in the spectrum of *Beta Lyræ;* and moreover, that the bright lines were so shifted towards the red end of the spectrum with respect to the dark lines as to indicate the tremendous relative velocity of more than 500 miles a second in the two masses to which the lines were respectively due. As to the other lines there was dispute. Lockyer maintained that they were the same that are found in the nebulæ; other observers, no doubt correctly, identified them with certain lines which are conspicuous in the spectrum of the solar chromosphere in every important eruption. The star faded to apparent extinction in April, 1892, but most unexpectedly brightened up again the following August, though not so as to be seen with the naked eye; with the telescope it is still visible. Its spectrum, however, has undergone a remarkable transformation, many of the lines which were formerly most conspicuous having disappeared, while others have taken their place, so that at present it is unquestionably a nebular spectrum. As Mr. Campbell, of the Lick Observatory, who has perhaps the best right to speak authoritatively, puts it, "The lines of the present spectrum do not occupy the positions of the lines in the February

spectrum, nor the positions of the lines in the solar chromosphere, nor the positions of the lines in the spectra of any of the bright-lines stars; they do occupy the positions of the lines in the nebulæ, and the spectrum resembles nebulæ spectra as closely as well known nebulæ spectra resemble each other." This is said in answer to some high authorities who find it difficult to admit so surprising a fact as such a transformation. It certainly looks as if we had to do with a reversion of the ordinary course of stellar development; instead of the formation of a star by the slow condensation of a nebula, we seem to have the sudden formation of a nebula by the violent explosion of a star. But speculation on so small a basis of fact is hardly sound.

I must not close without a reference to the important, though unpretending, catalogue of variable stars just published by Mr. Chandler, of Cambridge, who, since the death of Schönfeld, may be regarded as at the head of the department of variable stars, so far at least as relates to the mathematical aspects of the subject. The first step to any real mastery of it must be an accurate collection of facts, such as this catalogue embodies. It gives a list of all the stars which are certainly known at present to be variable, 260 in number (62 of them naked-eye stars), and adds a subsidiary list of 100 more which are more or less strongly suspected. Of the 260, about 35 are known to be irregular and unpredictable in their variations, and about as many more are still in doubt as regards the periodicity of their changes. The remaining 190 are clearly periodic, and Mr. Chandler gives for each of them the formula by means of which its variations can be predicted, thus embodying in a few modest figures the result of an enormous amount of skillful labor. Ten of the variables belong to the *Algol* class, about 25 to that of *Beta Lyræ*, and the rest resemble *Omicron Ceti* more or less perfectly. It should be added also that the list of variables is constantly growing—chiefly, of course, among the telescopic stars.

THE LUMINIFEROUS ÆTHER.*

By Sir GEORGE G. STOKES.

I intend to bring before you to-night a subject which the study of light has caused me to think a good deal about: I refer to the nature and properties of the so-called luminiferous æther. This subject is, in one respect, specially fascinating, scientifically considered. It lies, we may say, in an especial manner on the borderland between what is known and what is unknown. In the study of it, it is quite conceivable that great discoveries may be made, and in fact great discoveries have already been made, and I may say even quite recently, and we do not at present know how much additional light on the system of Nature may be in store for the men of science; possibly even in the near future, possibly not until many generations have passed away. I will assume, as what is familarly known to you all, and what is well established by methods into which I will not enter, that the heavenly bodies are at an immense distance from our earth. More especially is this the case with the fixed stars. Their distance is so enormous that even when we take as a base line, so to speak, the diameter of the earth's orbit, which we know to be about 184,000,000 of miles, the apparent displacement of the stars due to parallax is so minute as almost to elude our investigation. Nevertheless that distance is more or less accurately determined in the case of a few of the fixed stars. But the vast majority, as we have every reason to believe, are at such an enormous distance that even this method fails with them.

To give a conception of the immense distance of the fixed stars, I will assume as known that light travels at the rate of about 186,000 miles in one second, a rate which would carry it nearly eight times round and round the earth in that time; and yet if we take the star which, so far as we know, is our nearest neighbor, it would take about four years for light from that star to reach the earth. Now as we see the fixed stars there must be some link of connection between us and them in order that we should be able to perceive them. Probably all of you know that two theories have been put forward as to the nature of light, as to the nature accordingly of that connection of

* Presidential address at anniversary meeting of Victoria Institute, June 29, 1893. (*Nature*, July 27, 1893; vol. XLVIII, pp. 306-308.)

which I have spoken. According to one idea, light is a substance darted forth from the luminous body with an amazing velocity: according to the other, it consists in a change of state taking place, propagated through a medium, as it is called, intervening between the body from which the light proceeds and the eye of the observer. For a considerable time the first of these theories was that chiefly adopted by scientific men. It was that, as you know, which Newton himself adopted; and probably the prestige of his name had much to do with the favorable reception which for a long time it received. But more recent researches have so completely established the truth of the other view, and refuted the old doctrine of emissions, that it is now universally held by scientific men that light consists in an undulatory movement propagated in a medium existing in all the space through which light is capable of passing.

This necessity for filling all space, or at least such an inconceivably great extent of space, with a medium, the office of which, so far as was known in the first instance, was simply that of propagating light, was an obstacle for a time to the reception by the minds of some of the theory of undulations. Men had been in the habit of regarding the inter-planetary and inter-stellar space as a vacuum, and it seemed too great an assumption to fill all this supposed vacuous space with some kind of medium for the sole purpose of transmitting light. Notwithstanding, even long ago strong opinions were entertained to the effect that there must be something intervening between the different heavenly bodies. In a letter to Bentley, Newton expresses himself in very strong language to this effect: "That gravity should be innate, inherent and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe that no man who has in philosophical matters a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent acting constantly according to certain fixed laws; but whether this agent be material or immaterial, I have left to the consideration of my readers."

What the nature of the connection between the earth and the sun, for example, may be whereby the sun is able to attract the earth and thereby keep it in its orbit—in other words, what the cause of gravitation may be—we do not know; for anything we know to the contrary, it may be connected with this intermediate medium or luminiferous æther. There are other offices, we believe, which this luminiferous æther fulfills, to which I shall have occasion to allude presently.

In connection with the necessity for filling such vast regions of space with this medium, a curious question naturally presents itself. We can not conceive of space as other than infinite, but we habitually think of matter as occupying here or there limited portions of space, as for example the different heavenly bodies. The intervening space we

commonly think of as a vacuum, and it is only the phenomena of light that led us in the first instance to think of it as filled with some kind of material. The question naturally presents itself to the mind—is this æther absolutely infinite like space? This is a question to which science can give no answer. Though we can not help thinking of space as infinite, yet when we turn our thoughts to some material existing in space perhaps we more readily think of it as finite than infinite. But if the æther, however vast the portion of space over which it extends, be really limited, we can hardly fail to speculate what there may be outside its limits. Space there might be wholly vacuous, or possibly outside altogether this vast system of stars and æther there may be another system subject to the same laws, or subject to different laws, as the case may be, equally vast in extent; and if there be, then so far as we can gather from such phenomena as are open to our investigation, there can be no communication between that vast portion of space in part of which we live and an ideal system altogether outside the æther of which we have been speaking.

But the properties of the æther are no less remarkable than its vast or even possibly limitless extent. Matter of which our senses give us any cognisance is heavy, that is to say, it gravitates toward other matter which agrees with it in so far as being accessible to our senses. The question presents itself to the mind, does the æther gravitate toward what we call ponderable matter? This is a question to which we are not able to give any positive scientific answer. If the æther be in some way or other connected with the cause of gravitation it would seem more likely that it itself does not gravitate toward ponderable matter.

Again, we have very strong reason for believing that ponderable matter consists of ultimate molecules. First, that supposition accords in the simplest way with the laws of crystallography. Chemical laws afford still stronger confirmation of the hypothesis, through the atomic theory of Dalton, now universally accepted. Comparatively recently, the deduction of the fundamental property of gases from the kinetic theory, as it is called, affords strong additional confirmation of that view of the constitution of matter. Still more recently, the explanation which has been afforded by that theory of that most remarkable instrument the "radiometer" of Crookes has lent further confirmation in the same direction. None of these evidences apply to the æther, and accordingly we are left in doubt whether it too consists of ultimate molecules, or whether on the other hand it is continuous, as we can not help conceiving space to be.

The undulatory theory of light was greatly promoted in the first instance by the known phenomena of sound, and the explanation which they received from the hydro-dynamical theory. Accordingly, since sound, as we know, consists of an undulatory movement propagated through the air (or it may be through other media), and depending

upon condensation and rarefaction, it was supposed naturally that light was propagated in a similar manner, by virtue of the forces brought into play by the condensation and rarefaction of the æther. But there is one whole class of phenomena which have actually no counterpart in those of sound; I refer to polarization and double refraction.

The evidence for the truth of the theory of undulations as regards the phenomena of common light depends in great measure upon the fact of interference and the explanation which the theory gives of the complicated phenomena of diffraction. But in studying the interference of polarized light, additional phenomena presented themselves which ultimately pointed out that the vibrations with which we are concerned in the case of the æther differ altogether in their character from those which belong to sound. The phenomena of the interference of polarized light prove incontestably that there exists in light an element of some kind having relation to directions transverse to that of propagation, and admitting of composition and resolution in a plane perpendicular to the direction of transmission according to the very same laws as those of the composition and resolution of forces, or velocities, or displacements in such a plane. This requires us to attribute to the æther a constitution altogether different from that of air. It points out the existence of a sort of elasticity whereby the æther tends to check the gliding of one layer over another. Have we no example of such a force in the case of ponderable matter? We have. We know that an elastic solid, which for simplicity I will suppose to be uncrystalline, and alike in all directions, has two kinds of elasticity, by one of which it, like air, tends to resist compression and rarefaction; while by the other it tends to resist a continuous gliding of one portion over another, and to restore itself to its primitive state if such a gliding has taken place. There is no direct relation between the magnitude of these two kinds of elasticity, and in the case of an elastic solid such as jelly the resistance to compression is enormously great compared to the resistance to a gliding displacement.

If we assume that in the æther there is really an elasticity tending to restore it to its primitive condition when one layer tends to glide over another, an elasticity which it appears to be absolutely necessary to admit in order to account for the observed laws of interference of polarized light, the question arises, can we thereby explain double refraction?

The earliest attempts to explain it in accordance with the theory of transverse vibrations were made by attributing to the æther a molecular constitution more or less analogous to that which we believe to exist in ponderable matter. Following out speculations founded upon that view, the celebrated Fresnel was led to the discovery of the actual laws of double refraction; the theory however which he gave was by no means complete, inasmuch as the results were not rigorously deduced from the premises. Cauchy and Neumann, independently and about

simultaneously, took up Fresnel's view of the constitution of the æther and applied it to explain the laws of double refraction. In their theory the conclusions arrived at were rigorously derived from the premises; but the results did not altogether agree with observation: that is to say, although they could by the adoption of certain suppositions be forced into a near accordance with the observed laws of double refraction, yet they pointed out the necessity of the existence of other phenomena which were belied by observation. Our own countryman Green was the first to deduce Fresnel's laws from a rigorous dynamical theory; although nearly simultaneously, MacCullagh arrived at a theory in some respects similar, though on the whole I think less satisfactory.

Still all these theories followed pretty closely the analogy of ponderable matter; and at least in the first three mentioned the æther was even imagined to consist of discrete molecules, acting on one another, like the bodies of the solar system regarded as points, by forces in the direction of the joining line, and varying as some function of the distance. I have already quoted the very strong language in which Newton rejected the idea of the heavenly bodies acting on one another across intervening spaces which were absolutely void. But the conception has nothing to do with the magnitude of the intervening spaces; and the conception of action at a distance across an intervening space which is absolutely void, is not a bit easier when the space in question is merely that separating two adjacent molecules, when the æther is thought of as consisting of discrete molecules, than it is when the space is that separating two bodies of the solar system, though in this latter case it may amount to many millions of miles. If the æther be in some unknown manner the link of connection whereby two heavenly bodies are enabled to exert on one another the attraction of gravitation, then according to the hypothetical constitution of the æther that we have been considering, we seem compelled to invent an æther of the second order, so to speak, to form a link of connection between two separate molecules of the luminiferous æther. But since the nature of the æther is so very different as it must be from that of ponderable matter, it may be that the true theory must proceed upon lines in which our previous conceptions derived from the study of ponderable matter are in great measure departed from.

If we think of the æther as a sort of gigantic jelly, we can hardly imagine but that it would more or less resist the passage of the heavenly bodies—the planets for instance—through it. Yet there appears to be no certain indication of any such resistance. It has been observed indeed in the case of Encke's comet, that at successive revolutions the comet returned to its perihelion a little before the calculated time. This would be accounted for by the supposition that it experienced a certain amount of resistance from the æther. Although at first sight we might be disposed to say that such a resistance would retard perihelion passage, yet the fact that it would accelerate it

becomes easily intelligible, if we consider that the resistance experienced would tend to check its motion, and so prevent it from getting away so far from the sun at aphelion, and would consequently bring it more nearly into the condition of a planet circulating round the sun in a smaller orbit.

Many years ago I asked the highest authority in this country on physical astronomy, the late Prof. Adams, what he thought of the evidence afforded by Encke's comet for the existence of a retarding force, such as might arise from the æther. He said to me that he thought we did not know enough as to whether there might not possibly be a planet or planets within the orbit of Mercury which would account for it in a different way. But quite independently of such a supposition it is worthy of note that the remarkable phenomena presented by the tails of comets render it by no means unlikely that even without the presence of a resisting medium, and without the disturbing force arising from the attraction of an unknown planet situated so near to the sun as not to have been seen hitherto, the motion of the head of a comet might not be quite the same as that of a simple body representing the nucleus, and being subject to the gravitation of the sun and planets and nothing else. It appears that the tails consist of some kind of matter driven from the comet with an enormous velocity by a sort of repulsion emanating from the sun. If the nucleus loses in this manner at each perihelion passage an exceedingly small portion of its mass, which is repelled from the sun, it is possible that the residue may experience an attraction towards the sun over and above that due to gravitation, and that possibly this may be the cause of the observed acceleration in the time of passing perihelion even though there be no resistance on the part of the æther. So that the question of resistance or no resistance must be left an open one.

The supposition that the æther would resist in this manner a body moving through it is derived from what we observe in the case of solids moving through fluids, liquid or gaseous, as the case may be. In ordinary cases of resistance, the main representative of the work apparently lost in propelling the solid is in the first instance the molecular kinetic energy of the trail of eddies in the wake. The formation of these eddies is however an indirect effect of the internal friction, or if we prefer the term—viscosity, of the fluid. Now the viscosity of gases has been explained on the kinetic theory of gases, and in the case of a liquid we cannot well doubt that it is connected with the constitution of the substance as not being absolutely continuous but molecular. But if the æther be either non-molecular, or molecular in some totally different sense from ponderable matter, we cannot with safety infer that the motion of a solid through it necessarily implies resistance.

The luminiferous æther touches on another mysterious agent, the nature of which is unknown, although its laws are in many respects known, and it is applied to the every-day wants of life, and its appli-

cations are even regulated by Acts of Parliament: I allude to electricity. I said that the nature of electricity is unknown. More than forty years ago I was sitting at dinner beside the illustrious Faraday, and I said to him that I thought a great step would have been made if we could say of electricity something analogous to what we say of light, when we affirm that light consists of undulations; and he said to me that he thought we were a long way off that at present. But, as I said relations have recently been discovered between light and electricity which lead us to believe that the latter is most closely connected with the luminiferous æther.

Clark-Maxwell showed that the ratio of two electrical constants (which are capable of being determined by laboratory experiments, and which are of such a nature that that ratio expresses a velocity) agrees with remarkable accuracy with the known velocity of light. This formed the starting-point of the electro magnetic theory of light which is so closely associated with the name of Maxwell.

ATOMS AND SUNBEAMS.*

By Sir ROBERT BALL, F. R. S.

In recent years an important change has taken place in the manner in which many physical problems are approached. The philosopher who now seeks an explanation of great natural phenomena not unfrequently finds much assistance from certain remarkable discoveries as to the ultimate constitution of matter. Many an obscure question in physics has been rendered clear when some of the properties of molecules have been brought to light. No doubt our knowledge of the natural history of the molecule is still vastly wanting in detail. It must however be admitted that we have traced an outline of that wonderful chapter in nature which is specially serviceable in the question which I now propose to discuss.

The problem before us may be stated in the following terms. We have to illustrate how the sun is enabled to maintain its tremendous expenditure of light and heat without giving any signs of appproaching exhaustion. It will be found that the atomic theory of the constitution of matter exhibits the mechanism of the process by which that capacity of the great luminary for supplying the radiation so vital to the welfare of mankind is sustained from age to age.

Let me here anticipate an objection which may not improbably be raised. Those who have paid attention to this subject are aware that the remarkable doctrine first propounded by Helmholtz removed all real doubt from the matter. It is to this eminent philosopher we owe an explanation of what at first seemed to be a paradox. He explained how, notwithstanding that the sun radiates its heat so profusely, no indications of the inevitable decline of heat can be as yet discovered. If the sun had been made of solid coal from center to surface, and if that coal had been burned for the purpose of sustaining the radiation, it can be demonstrated that a few thousand years of solar expenditure at the present rate would suffice to exhaust all the heat which the combustion of that great sphere of fuel could generate. We know however that the sun has been radiating heat, not alone for thousands of years, but for millions of years. The existence of fossil plants and animals would alone suffice to demonstrate this fact. We have thus to

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account for the extremely remarkable circumstance that our great luminary has radiated forth already a thousand times as much heat as could be generated by the combustion of a sphere of coal as big as the sun is at present, and yet, notwithstanding this expenditure in the past, physics declares that for millions of years to come the sun may continue to dispense light and heat to its attendant worlds with the same abundant prodigality. To have shown how the apparent paradox could be removed is one of the most notable achievements of the great German philosopher.

What Helmoltz did was to refer to the obvious fact that the expenditure of heat by radiation must necessarily lead to shrinkage of the solar volume. This shrinkage has the effect of abstracting from a store of potential energy in the sun and transforming what it takes into the active form of heat. The transformation advances *pari passu* with the radiation, so that the loss of heat arising from the radiation is restored by the newly produced heat derived from the latent reservoir. Such is an outline of the now famous doctrine universally accepted among physicists. It fulfils the conditions of the problem, and when tested by arithmetical calculation it is not found wanting.

But the genuine student of nature loves to get to the heart of a great problem like this. He loves to be able to follow it, not through mere formulæ or abstract principles, but so as to be able to visualise its truth and feel its certainty. He will therefore often desire something in addition to the bare presentation of the theory as above stated. It may be no doubt sufficient for the mathematician to know that the total potential energy in the sun, due to the dispersed nature of its materials, is so vast that as contraction brings the materials, on the whole, somewhat nearer together, the potential energy thus surrendered is transformed into a supply of heat quite adequate to compensate for the losses arising from the radiation by which the contraction was produced. The student who admits—and who is there that does not admit?—the doctrine of the conservation of energy, knows that in this argument he is on thoroughly reliable ground. At the same time the argument does not actually offer any very clear conception, or indeed any conception at all, of the precise *modus operandi* by which, as the active potential energy vanishes, its equivalent in available heat appears. I have always felt that this was the unsatisfactory part of an otherwise perfect theory. It was therefore with much interest that I became acquainted a short time ago with a development of the molecular theory of gases, which afforded precisely what seemed wanted to make every link in the chain of the great argument distinctly perceptible. I make no doubt that the notions which have occurred to me on this subject must have presented themselves to others also. I have however not read in print or heard in conversation any use made of the illustration that I am going to set forth. I feel therefore confident that even if it be known at all, it is certainly not generally known

among the large and ever-increasing circle of readers to whom the great questions of physics are of interest.

The division of matter into the three forms of solids, liquids, and gases has acquired in these days a special significance now that the constitution of matter is becoming in some degree understood. First let it be noted that, though matter is capable of subdivision to a certain extent, yet that there is a limit beyond which subdivision could not be carried. This statement touches upon the ancient controversy as to the infinite divisibility of matter. Even still we can find the statement in some of our old text-books that there is no particle of matter so small that it could not be again subdivided into half. No doubt (so far as most ordinary experience goes) this statement may be unquestionable. It is quite true that we do not often reduce matter to fragments so small that each of them shall be insusceptible of further conceivable division. But, to illustrate the natural principle now under consideration, let us take the example of a body which is itself composed of but a single element. Think for instance of a diamond, which is, as we all know, a portion of crystallized carbon. It is true that the reduction of diamonds to powder is a laborious process. Still, diamond dust has to be produced in the finishing of the rough stone, and this element will serve the purpose of our present argument better than a substance of a composite nature. Each particle of the diamond dust is, of course, as much a particle of carbon as was the original crystal. We may however suppose that by a repetition of the process a reduction of the diamond dust to powder still finer is accomplished. The grains thus obtained may have become so minute that they have ceased to be visible to the unaided eye, and require a microscope to render them perceptible: but even after this comminution each of these particles is still a veritable diamond. It possesses the properties, optical, chemical, and mechanical, of the original gem, from which it differs merely in the attribute of size. Even when the disintegration has been carried to such a point that each individual particle can be only just perceived by the keenest power of the most powerful microscope, there is still no indication that the particles cease to possess the characteristics of the original body.

These facts being undoubted, it was perhaps not unnatural to suppose that the reduction could be carried on indefinitely, and that even if the smallest fragment of diamond which could be seen in a powerful microscope were reduced to a millionth part, and each of those to a million more, yet that the ultimate particles thus reached would be diamonds still. Now, however, we know that that is not the case. The smallest particle visible under a microscope might indeed be crushed into a thousand parts, and each one of those parts, though wholly inappreciable to our sense of touch or vision, would nevertheless be a genuine diamond. If however the subdivision be carried on until the particles produced are, roughly speaking, one-millionth part of the bulk of the smallest

objects which could be seen in the microscope, we then approach the limits of partition of which the diamonds would be susceptible. We now know that there is an atom of diamond so small that it must refuse to undergo any further division. This ultimate atom, be it observed, is not an infinitely small quantity. It has definite dimensions; it possesses a definite weight. All such diamond atoms are precisely alike in weight, and probably in other characteristics. It might be thought that if this atom has finite dimensions, it is, at all events, conceivable that it should admit of further subdivision. In a certain sense this is, no doubt, the case. The diamond atom is made up of parts and being so made it is of course conceivable that those parts could be separated. The important point to notice is, that no means known to us could produce this separation, while it is perfectly certain that if the decomposition of the atom of diamond into distinct parts could be affected, those parts would not be diamonds at all, nor anything in the least resembling diamonds.

What we have said as regards the element carbon may be extended to every other elementary substance. Sulphur is familiarly known in a form of extreme subdivision, and each little particle of sulphur could be further comminuted to a certain point beyond which any further partition would be impossible. So too any composite body, such for example as a lump of sugar, admits of being decomposed into molecules so small that any further separation would be impossible if the molecule were still to remain sugar. No doubt, a separation of the molecule of any composite body into constituent atoms of other elements is not alone possible but is incessantly taking place.

The first step in our knowledge of the constitution of matter has been taken when we have come to recognize that every body is composed of a multitude of extremely, but not infinitely, small molecules. The next point relates to the condition in which these molecules are found. At first it might be thought that in a solid, at all events, the little particles must be clustered together in a compact mass. If we depended merely on sensible evidence it would seem that a lump of iron, if constituted from molecules at all, must be simply a cohering mass of particles, just as a multitude of particles of sand unite to form a lump of sandstone. But the truth is far more wonderful than such a belief would imply. Were the sensibility of our eyes so greatly increased as to make them a few million times more powerful than our present organs, then indeed the display of the texture of solid matter would be an astonishing revelation. It would be seen that the diamond atoms, which, when aggregated in sufficient myriads, form the perfect gem, were each in a condition of rapid movement of the most complex description; each molecule would be seen swinging to and fro with the utmost violence among the neighboring molecules. It would be seen quivering all over under the influence of the shocks which it would receive from the vehement encounters with other molecules which occur millions of times in each

second. Such would be the minute anatomy of the diamond. The well-known properties of such gems seem, at first sight, wholly at variance with the curious structure we have assigned to them. Surely, it may be said that the hardness and the impenetrability so characteristic of the diamond refute at once the supposition that it is no more than a cluster of rapidly moving particles. But the natural philosopher now knows that his explanation of the qualities of the diamond holds the field against all other explanations. The well-known impenetrability of the diamond seems to arise from the fact that when you try to press a steel point into the stone you fail to do so because the rapidly moving molecules of the gem batter the end of the steel point with such extraordinary vehemence that they refuse to allow it to penetrate or even to mark the crystallized surface. When you cut glass with a diamond it is quite true that the edge, which seems so intensely hard, is really composed of rapidly moving atoms. But the glass which is submitted to the operation is also merely a mass of moving molecules, and what seems to happen is that, as the diamond is pressed forward, its several particles, by their superior vigor, drive the little particles of glass out of the way. We do not see the actual details of the myriad encounters in which the diamond atoms are victorious over the glassy molecules; we only discern the broad result that the diamond has done its work, and that the glass has been cut.

It may well be asked how we know that matter is constituted of molecules in intensely rapid movement. The statement seems at the first glance to be so utterly at variance with our ordinary experience that we demand, and rightly demand, some convincing proof on the matter. There are many arguments by which the required demonstration can be forthcoming. The one which I shall give is not perhaps the most conclusive, but it has the advantage of being one of the simplest and the most readily intelligible.

Let us see if we can not prove at once that the molecules in, let us say, a piece of iron must be in movement. Suppose that the iron is warmed so that it radiates heat to a perceptible extent. We know that the heat which, in this case, affects our nerves has been transmitted from its origin by ætherial undulations. Those undulations have undoubtedly been set in motion by the iron, and yet the parts of the metal seem quite motionless relatively to each other, notwithstanding that they possess the power of setting the æther into vibration. It is impossible that such vibrations could be produced were it not that there is in the iron a something which vibrates in such a manner as to communicate the necessary pulses to the æther. It therefore follows that in the texture of the solid iron there must be some molecular movement, timed in such a way as to impart to the æther the actual vibrations which we find it to possess. The argument in this case may be illustrated by the analogous phenomena presented in the case of sound. As we listen to the notes of a violin, what we

actually perceive are vibrations communicated through the air to the auditory apparatus. We can trace these aerial vibrations back to their source, and we find they originate from the quivering of the violin under the influence of the bow of the performer. Were it not for these vibrations of the instrument the aerial vibrations would not be produced, and the corresponding sounds would not be heard. Far more delicate than the atmospheric waves of sound are the ethereal waves corresponding to light or to heat, but none the less must these latter also originate from the impulse of some vibrating mass. It is thus apparent that a hot piece of iron, however still it may seem, must be animated by an excessively rapid molecular movement. Nor is the validity of this conclusion impaired even if the iron be at ordinary temperature. We know that a body which is no hotter than the surrounding bodies is still incessantly radiating heat to them and receiving heat from them in return. Thus we are led to the conviction that a piece of iron, whatever be its temperature, must consist of atoms in a state of lively movement. The important conclusion thus drawn with regard to iron may be equally stated with respect to every other solid, or, indeed, every other body, whether solid, liquid, or gaseous. All matter of every description is not only known to be composed of molecules, but it is also now certain that those molecules are incessantly performing movements of a very complex type.

A closer study of this subject will be necessary for our present purpose, and it will be convenient to examine matter in that state in which it is exhibited in its very simplest type from the molecular point of view. This condition is not presented, as might at first be supposed, when the matter is solid, like a diamond, or like a piece of iron. Even in a liquid the complexity of molecular constitution, though somewhat less than in the case of a solid, is still notably greater than in matter which has the gaseous form. The air that we breathe is matter almost of the most simple kind, so far as molecular constitution is concerned. It should however be noted, that as air consists of a mixture, it would be better for our purpose to think of a gas isolated from any other element. Let us take the case of oxygen, the most important constituent of our atmosphere.

Like every other element, oxygen is composed of molecules, and those molecules are in a state of rapid motion. It might be expected that the affinity by which the different molecules were allied in the case of a gas should be of the simplest nature, and this is indeed found to be the case. Notwithstanding that oxygen is an invisible body, and notwithstanding that the molecules are so excessively minute as to be severally quite inappreciable to our senses, yet we have been able to learn a great deal with regard to the constitution of the molecules of this gas. The mental eye of the philosopher shows him that though the oxygen with which a jar is filled appears to be perfectly quiescent, yet that quiescence has there no real existence. He knows that oxygen

consists of myriads of molecules identical in weight and in other features, and darting about one among the other with velocities which vary perhaps between those of express trains and those of rifle bullets. He sees that each little molecule hurries along quite freely for a while until it happens to encounter some other molecule equally bent on its journey, and then a collision takes place. Perhaps it would be more correct to say that what usually happens is that the two impinging molecules make a very close approach; then each of them so vehemently attracts the other as to make it swerve out of its course and start it off along a path, inclined, it may be, even at a right angle to that which it previously pursued. The molecules in a gas at ordinary pressures are so contiguous that these encounters take place incessantly; in fact, we are able to show that each individual molecule will probably experience such adventures some millions of times in the course of each second. We are able to calculate the average velocity with which the several molecules move when the gas has a certain temperature. We know how to determine the average length of the free path which each molecule traverses in the interval between two consecutive encounters. We are able to trace how all these circumstances would vary if, instead of oxygen gas, we took nitrogen, or hydrogen, or any other body in the same molecular state. It is in fact characteristic of every gas that each molecule wanders freely, subject only to those incessant encounters with other similar wanderers by which its path is so frequently disturbed. If two gases be placed in the same vessel, one being laid over the other, it will presently be found that the two gases begin to blend; ere long one gas will have diffused uniformly through the other, so that the two will have become a perfect mixture just as the oxygen and nitrogen have done in our own atmosphere. The molecular theory of gases explains at once the actual character of the operation by which diffusion is effected. Across the boundary which initially separates the two gases certain molecules are projected from either side, and this process of interchange goes on until the molecules become uniformly distributed throughout.

There is indeed nothing more remarkable than the fact that information so copious and so recondite can be obtained in a region which lies altogether beyond the direct testimony of the senses. Just as the astronomer staggers our powers of conception by the description of appalling distances and stupendous periods of time, and relies with confidence on the evidence which convinces him of the reality of his statements, so the physicist avails himself of a like potent method of research to study distances so minute and times so brief that the imagination utterly fails to realize them.

In the case of a liquid, the freedom enjoyed by the molecules is considerably more restricted than in the case of a gas. It would seem that in the denser fluid there can be no intervals of undisturbed travel permitted to a molecule; it is almost incessantly in a state of encounter

with some other similar object. When a molecule in a liquid breaks away from its association with one group, it is only because it has entered into alliance with another. As however two liquids will very frequently blend if so placed that diffusion be possible, we have a proof that, though the transference of a particular molecule through the liquid may be comparatively slow, yet it will gradually exchange association with one group for association with another, and may in this way travel throughout any distance to which the liquid extends.

In the case of a solid there is still further limitation imposed on the mobility of each separate molecule. It is now no longer permitted to make excursions throughout the entire volume of the body. Each molecule is in rapid motion, it is true, but those movements are confined to gyrations within minutely circumscribed limits. Two solids placed in contact do not generally diffuse one into the other, the incapacity for diffusion being the direct consequence of the inferior degree of mobility possessed by the molecules in this condition of matter.

It is known that the immediate effect of the application of heat is to increase the velocities with which the molecules move. Apply heat, for instance, to the water in a kettle; the moving molecules of water are thereby stimulated to even greater activity and it will occasionally happen that the velocity thus acquired by a molecule becomes so great that the little particle will swing clear away from the influence of the other molecules with which it had been associated. When this takes place in the case of a sufficient number of molecules, they dart freely from the surface of the liquid, thus producing the effect which in our ordinary language we describe as giving off steam. If therefore a volume of gas be heated, the velocities with which its molecules are animated will be in general increased. As the molecular velocities throughout the extent of the gas are on the whole augmented, it is quite plain that the intensities of the shocks experienced by the molecules in their several encounters will be also accentuated. The more rapidly moving particles will strike each against the other with increased violence, and the contemplation of this single fact leads us close to one of nature's greatest secrets.

Let us think of the abounding heat which is dispensed to us from the sun. That heat comes, as we know, in the form of undulations imparted to the æther by the heated matter in the sun, and transmitted thence across space for the benefit of the earth and its inhabitants. I have already explained that these vibrations in the æther must take their rise from molecular movements, and it is important to notice that the character of the vibrations in the æther enables us to learn to some extent the precise description of molecular movements which alone would be competent to produce the particular vibrations corresponding to radiant heat. At first it might be thought that it was the rapid movements of translation of the molecules themselves, as entire if extremely minute bodies, which caused the ætherial vibration, but

this is not so. We must carefully observe that there is another kind of molecular motion besides that which the molecule possesses as a whole. We have hitherto been occupied only with the movements of each molecule as a little projectile pursuing its zigzag course, each turn of the zigzag being the result of an encounter with some similar molecule belonging to the same medium. But we have now to observe that the molecule itself is by no means to be regarded as a simple rigid particle; indeed, if it were so it is certain that we should receive no heat at all from the sun. We have the best reasons for believing that the molecule of matter, so far from resembling a simple rigid particle, is an elaborate structure, whose parts are in some degree capable of independent movement. It will not, indeed, be necessary for us to adopt the splendid hypothesis of Lord Kelvin, which supposes that molecules of matter are merely vortex rings in that perfect fluid, the æther. It seems difficult to doubt that this doctrine represents the facts, but if anyone should reject it, then I have only to say that its assumption is not required for our present argument. All that is necessary for us is to regard each molecule as somewhat resembling an elastic structure made of parts which can quiver like springs, and so arranged as to be susceptible of many different modes of vibration. We are to suppose that each molecule, in addition to the energy which it possesses in virtue of its movement of translation as a whole, has also a store of energy corresponding to the oscillations of its electric springs. We can, in fact, in some cases determine the ratio which exists between the amount of energy which is, on the average, possessed by molecules in consequence of their velocities of translation, and the amount of energy which they possess in consequence of the vibrations by which their several parts are animated. It is these internal molecular vibrations which are of essential importance in our present inquiry. It is believed that the radiation of light or of heat generally takes rise in the impulses given to æther by the internal molecular vibrations. Do we not know that the essential characteristic of those ætherial movements which correspond to radiant light and heat is that they have the nature of oscillations? Such could not be imparted by mere rectilinear movements of the molecules as a whole. They must be due to those internal oscillations by which the actual molecules are animated.

No doubt it is difficult to realize that much can be learned with regard to the performances that actually go on in the internal parts of a molecule, especially when it is remembered that each molecule in its entirety is so extremely minute as to be entirely beyond the reach of our organs of sense. It is nevertheless impossible to doubt that the statements just made correspond to the veritable facts of nature. It would be impracticable here to go into any complete detail with regard to the evidence on this subject; I can only sketch an outline of it. Let us take, perhaps as the simplest case, that presented by hydrogen.

At the ordinary temperature of the air, hydrogen is of course invisible; this means that the vibrations in the interior of the molecules are not sufficiently vehement to impart pulses to the æther with the energy that would be required to produce visual effects. Now, let us suppose that the hydrogen is heated. The effect of heating is to impart additional speed to the molecules of the gas, and consequently when the molecules happen to come together their encounter is more violent. The effect of such an occurrence on one of these little elastic bodies is to set it quivering with greater vehemence in those particular modes of vibration for which it is tuned. If the temperature of the gas has been raised sufficiently high, as it can be by the aid of electricity, then the internal energy acquired by the molecules, in consequence of the increased vehemence of their collisions, has become so great that they are able to impart pulses to the æther with sufficient intensity to affect our nerves of vision; thereupon we declare that the hydrogen is now so hot as to have become luminous. Suppose we employ a spectroscope for the purpose of studying the particular character of the light which the glowing hydrogen dispenses. It will appear that the spectrum consists of a definite number of bright lines. We know that each one of these lines corresponds to a particular period of vibration of the æther, and hence we see that the light emitted by the hydrogen does not consist of vibrations of all periods indiscriminately, but only of certain particular waves which are in unison with the oscillations to which the internal parts of the molecule of hydrogen are adopted. Had we examined the spectrum of some other gas in a state of incandescence we should have found a wholly different system of lines from those pertaining to hydrogen. This demonstrates that the molecules of one gas differ essentially from those of another in respect to the character of the internal vibrations which they are adapted to perform. The extraordinary activity of the movements which take place within the molecules may be appreciated from the following facts. We know that the wave corresponding to one of the hydrogen lines has a length of about the forty-thousanth of an inch; we also know that in a single second of time light travels over a space of 186,000 miles; a simple calculation will, therefore, assure us that certain vibrations in the molecules of hydrogen corresponding to this particular undulation must take place with such an extraordinary frequency that about 460 millions of millions of them are performed in each second of time.

Provided with these conceptions we shall now, I think, be able to see without difficulty how it is that the sun's heat is sustained. We may, for our present purpose, think of the great luminary as a mass of glowing gas. It is quite true that the physical condition of the matter in the interior of the tremendous globe can hardly be that which we ordinarily consider as gaseous. But this need not affect our argument. It is undoubtedly true that those portions of the solar atmosphere from which the light and heat are mainly dispensed are

gaseous in their character, or, at all events, come sufficiently near to matter in the gaseous state to permit the application of the line of argument with which we have hitherto been engaged. In consequence of the vast mass of the sun the gravitation with which it draws all bodies towards it is very much greater than the gravitation on the surface of the earth. On our globe we know that the effect of gravitation is to impart to any body near the surface velocity directed towards the earth's center at the rate of 32 feet per second. The sun is more than three hundred thousand times as massive as the earth; we can not however assert that the gravitation is increased in the same proportion, because, on account of the vast size of the sun, a particle at its surface is more than a hundred times farther away from the solar center than a body on the surface of the earth is from the terrestrial center. It can however be shown, that taking these various matters into account, the actual intensity of gravitation at the solar surface is sufficient to tend to impart to all objects an increase of velocity towards the sun's center at the rate of 457 feet per second. This would apply not only to a meteorite, or other considerable mass, which is falling into the sun; it would be equally true of an object as small as a molecule. Every one of the myriads of gaseous molecules in the outer regions of the solar atmosphere must be constantly acted upon by this attractive force, which tends in the course of each second to add to them a downward velocity at that rate per second which has already been stated. It is quite true that to a great extent the effect of this attraction is masked by counteracting tendencies. In particular we may mention that inasmuch as the density of the solar atmosphere increases as the sun's center is approached, the flying molecule genererally finds itself more obstructed by encounters with other molecules when it is descending than when it is ascending.

We may here contrast the condition of the atmosphere on the earth with the condition of the solar atmosphere. Each molecule in our air, being acted upon by terrestrial gravitation, has thereby a tendency to fall downward with a velocity continually increasing at the rate of 32 feet per second. As however the terrestrial atmosphere has long since reached a stable condition, in which it undergoes no further contraction, the effect of gravitation in adding velocity to the molecules is so completely masked by the counteracting tendencies, that on the whole, there is no continual increase of molecular velocities downward due to gravitation. Were such an increase at present going on, we should necessarily find that the terrestrial atmosphere was decreasing in volume, and ever becoming more condensed in its lower strata. It is however well known that no such changes as are here implied are taking place. The essential difference between the earth and the sun, (so far as the matter now before us is concerned,) is to be found in the fact that as the sun has not yet passed into the form of a rigid body, it is still contracting at a rate very much greater than that at which a

body grown so cold as the earth draws its particles closer together. The molecules in the solar photosphere accordingly yield to a certain extent to the gravitation which constantly seeks to draw them down. The counteracting tendencies can not in the sun, as they do in the earth, mask the direct and obvious effect of gravitation. The consequence is that the intense attraction which is capable of adding velocity to the molecules at the phenomenal rate of 457 feet per second, is permitted to accomplish something, and thus increase the average speeds with which the molecules hurry along. To express the matter a little more accurately, we should say that the downward velocity imparted by gravitation, being compounded with the velocities otherwise possessed by the molecules, tends, on the whole, to increase the rate at which they move.

We shall now be able to discern what actually takes place as the sun contracts by dispersing heat, and in consequence of its decline in bulk finds a store of energy liberated which it is permitted to use for the purpose of sustaining its radiating capacity. Owing to the intense heat which prevails in the photosphere, the molecules must there be in very rapid movement; their mutual encounters must be of the utmost vehemence, and their internal vibrations, which are the consequences of the shocks in the encounters, must be correspondingly energetic. It is, as we have seen, these internal molecular vibrations which set the æther in motion, and thus dispense solar heat and light far and wide through the universe. But this the molecules can only do at the expense of the energy which they possess in virtue of their internal vibrations. Unless therefore the internal molecular energy were to be in some way recuperated from time to time, the radiating power must necessarily flag. It is now plain that the necessary recuperation takes places in the successive encounters. A molecule whose internal energy of vibration is becoming exhausted by the effort of setting the æther into vibration presently impinges against some other molecule, and in consequence of the blow is again set into active vibration which permits it to carry on the work of radiation anew, until its declining energies have again to be sustained by some similar addition arising from a fresh collision. Of course, we know that the internal molecular energy thus acquired can not be created out of nothing. If the molecule receives such accessions of internal energy, it must be at the expense of the energy which is elsewhere. Obviously the only possible source of such energy must be found in the movement of the molecule as a whole, that is to say, in the velocity of translation with which it rushes about among the other molecules. Thus we see that the immediate effect of expenditure of heat or light by radiation is to diminish the internal energies of the molecules. These energies are restored by the transference of energy obtained from the general velocities of the molecules regarded as moving projectiles. It follows that the velocities of the several particles must on the whole tend to decline; in other

words, that the temperature tends to fall. What we have to discover is the agent which at present prevents the solar temperature from falling. We want therefore to ascertain the means by which the molecular velocities are preserved at the same average value, notwithstanding that there is a constant tendency for these velocities to abate in consequence of the losses of light and heat by radiation. We have already explained how the gravitation of the sun constantly tends to impart additional downward velocity to the molecules in its atmosphere. This is precisely the action which we now require. The contraction of the sun tends to an augmentation of the molecular velocities, and this augmentation just goes to supply the loss of velocities which is the consequence of the radiation. A complete explanation of the maintenance of the sun's heat is thus afforded. Observation no doubt seems to show that the capacity for radiation is at present sensibly constant, and this being so, we see that the gain of molecular velocities from gravitation and their losses from radiation are at present just adapted to neutralize each other. Nothing however that has as yet been said demonstrates that the efficiency of the sun for radiating light and heat must always be preserved exactly at its present value.

It is quite possible that if we had the means of studying the sun heat for a hundred thousand years, we might find that the capacity for radiation was slightly decreasing, or it may be that it would be slightly increasing, for it is at least conceivable that the gain of molecular velocity due to gravitation may, on the whole, exceed the loss due to the dispersal of energy by radiation. On the other hand, it is of course possible that the acquisition of velocity by gravitation, though nearly sufficient to countervail the expenditure by radiation, may not be quite enough, in which case the sun's temperature would be slowly declining.

It must not however be supposed that the argument which we have been here following attributes eternal vigor to the great luminary. It will be noted that it is of the essence of the argument that the contraction is still in progress. If the contraction were to cease, then the restitution of velocity by gravitation would cease also, and the speedy dispersal of the existing heat by radiation would presently produce bankruptcy in the supply of sunbeams. Indeed, such bankruptcy must arrive in due time, when, after certain millions of years, the sun has so far contracted that it ceases to be a gaseous mass. The vast accumulated store of energy which is now being drawn upon to supply the current radiation, will then yield such supplies no longer. Once this state has been reached, a few thousand years more must witness the extinction of the sun altogether as a source of light, and the great orb, at present our splendid luminary, will then pass over into the ranks of the innumerable host of bodies which were once suns, but are now suns no longer.

FUNDAMENTAL UNITS OF MEASURE.*

By T. C. Mendenhall,

Superintendent of the U. S. Coast and Geodetic Survey.

Engineering is the art of construction; but to limit it to this would be to restrict its meaning much within the range of the ordinary use of the word. In a broader sense, engineering includes all operations whose object is the utilization of the forces of nature in the interests of man. It is both an art and a science, and as a science it consists for the most part of mathematics applied to physics and mechanics. It is of necessity, therefore, a measuring science, and a congress of engineers ought, in the nature of things, to be interested in anything relating to progress in metrology.

Fortunately the literature of this subject is neither scanty nor difficult of access. Much attention has been given to it in all parts of the world during the last half of this century, and in the United States especially numerous and valuable papers and reports upon the subject of weights and measures have appeared during this period. Indeed, it would be difficult, if not impossible, to contribute to either the historical or the controversial aspect of the question anything new and of notable value.

In spite of an extensive and widely circulated literature, however, it is very distinctly in evidence that the origin and genesis of the units of measure in customary use in the United States and among most English-speaking people, and their relation or want of relation to each other, are matters concerning which many engineers are not well informed.

Perhaps not a large majority of members of the profession in good standing would be able to answer accurately the question, What is a yard? or What is a pound? In view of this fact no excuse need be offered for presenting a statement of facts relating to fundamental standards in this country at the present time, and for the sake of clearness this statement will be prefaced by a brief consideration of the principles involved in the evolution and selection of standards, together with a résumé of genealogical history, showing their origin and ances-

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try. Of the latter little detail will be given, as the extensive and easily accessible literature upon the subject renders it unnecessary.

The measure of a magnitude is its numerical evaluation. In a direct way this is accomplished by ascertaining how many times it contains another magnitude of the same kind or nature which is adopted as a unit. Thus a length is selected as a unit for the measurement of length, a volume for the measurement of volume, a time for time measurement, and so on. At first it seems that this condition of sameness of the unit and the thing measured is a necessity. A little reflection will show, however, that it is open to the objection that it naturally, although perhaps not necessarily, leads to an almost indefinite multiplication of independent units. The discovery and development of inter-relations among measurable magnitudes, which has gone on from the earliest times, has tended towards a reduction in the number of units and, consequently, to a great simplification of the whole subject of metrology. So simple and evident a device as relating the unit of volume to the unit of length has only been satisfactorily realized in comparatively modern times; and, with a single exception, it may be affirmed that units of volume now in use were originally in no way related to units of length, most of them being of accidental and now unknown origin. That a legal bushel in the United States must contain 2150·42 cubic inches is convincing evidence that the foot or the yard has no place in its ancestry, and although there is a plausible explanation of the fact that a gallon contains 231 cubic inches, it points only to a modified volume and not a selected one.

Many interesting illustrations of the great advantage gained by neglecting the principle that "like measures like" might be given, and one or two will, perhaps, be found instructive. In observing that property of matter known as "conductivity," either as to heat or electricity, qualitative or relative conclusions were for a long time all that was required. It was at first sufficient to say and to know that one substance conducted heat or electricity better or worse than another, but with the advance of knowledge of physics it became desirable, and often necessary, to give numerical expression to these relations. In such cases as this the practice has usually been to select some particular substance which possesses the property in question in a higher or in a lower degree than any other and adopt it as a standard. Thus barely a quarter of a century ago conductivities of different bodies for heat or electricity were expressed in terms of copper or silver; a lamp-black surface was the standard for radiation or absorption, and in most instances the standard was arbitrarily rated at 100. The literature of science contains many examples of elaborate and otherwise valuable investigations which are rendered quite worthless by the uncertain and unscientific units of measure employed. An example of the persistent use of this principle is to be found in the still common mode of expressing the density of matter by referring it to the density of a certain

kind of matter, namely, water, the numerical representation of the ratio being known as "specific gravity." It has taken some years for even scientific men to fully appreciate the objectionable features of this sort of metrology, because it has required some time to prove beyond doubt that all kinds of copper or silver do not conduct alike, nor do all samples of lampblack radiate alike; and also that the conditions under which the density of water is constant are difficult of realization.

Another factor which has been, up to a very recent time, of first importance in the selection of standards is the tendency to seek in nature something of constant dimensions or invariable mass which possesses that general availability essential to adoption as standard. The nomenclature of metrology bears testimony to this. In our own customary system of weights and measures the occurrence of such units as the foot, hand, grain, ell, etc., tells of the frequent recourse to natural units. This is not alone characteristic of earlier and ruder systems, but in modern metrology we have recorded the efforts of scientific men to realize this theoretically desirable condition in the selection of the quadrant of the earth, the length of a seconds pendulum, and the wave length of a particular kind of light for linear standards. The only natural standard which up to this time can be said to have satisfied the requirements is the unit of time, which is the sidereal day. This might itself be considered a derived rather than a fundamental unit, and, indeed, it is difficult to conceive of any time unit other than one based on motion. The motion of the earth is assumed to be a uniform rotatory motion, and the unit is the duration of a single revolution. Vibratory or periodic motion seems to offer many advantages as a time standard, and various forms have been suggested from time to time. It has been shown that the period of a freely suspended invariable pendulum furnishes in practice a more uniform and constant time unit than the best clocks or chronometers. All standards of this type depend on the persistence of gravity, however, and of this we can not be assured. The prime requisites of a standard are constancy and universal availability, and as the present time unit, the sidereal day, possesses these in a high degree it is not likely that it will soon be supplanted. It would be extremely desirable, however, if a unit of time could be devised which would survive such terrestrial or celestial disturbances as would materially alter the revolution of the earth upon its axis. Something of this kind is necessary if time observations made during the present cycle are to be available in future ages, and it is possible that the determination of the relation of the wave length of light to the generally accepted unit of length may indirectly furnish a time unit possessing this characteristic in a high degree.

The greatest advance in the science of metrology in modern times is essentially due to Gauss, and it consists of the so-called "absolute" system of measurement. Quite as much as to the author of this ingenious system metrologists are indebted to the celebrated British Asso-

ciation Committee on Units, led by Lord Kelvin, and including such men as Clerk Maxwell, Foster, Stoney, Fleeming Jenkin, Siemens, Bramwell, Adams, Balfour Stewart, and Everett. Evincing a freedom from national prejudices worthy of the distinguished body which they represented, this committee placed the system of Gauss upon a firm and enduring basis by deriving its fundamental units from the only system of weights and measures which, starting from a scientific basis and constructed upon scientific principles, has ever found favor among a considerable number of people, and which has now become well-nigh universal.

The tendency of the absolute system is towards simplicity through a reduction of the number of fundamental units to a minimum, while at the same time it affords every facility for the multiplication of derived units to meet the demands of convenience in practice. But however complex and numerous these derived units may be, they all grow out of the same elements, and are therefore easy of comparison and interchange.

It is not too much to say, and it is important that it should be said, that the beauty, simplicity, and convenience of this system are not yet fully understood and appreciated by many engineers who might be greatly benefited by its use. As a single illustration, reference may be made to the still very general use of the foot-pound as a unit of work and energy. Let no one imagine that the objection to this unit lies in the fact that units of the metric system are not used, for kilogram-meter, which is also very common, is equally objectionable. The difficulty rests in the introduction of a variable, and in this instance unnecessary magnitude, namely, the force of gravitation. If the fundamental units, foot, pound, and second, be used, we have a unit of work sometimes called the "foot-poundal," and if the centimeter, gram, second system be used, we have the well-known "erg." These units are vastly more convenient in practical use than their gravitation relatives, besides being invariable, whenever and wherever the units of length, mass, and time are invariable.

Modern scientific metrology may be said to rest upon a few simple principles which may be summarized as follows:

The number of independent fundamental units should be minimum. In general not more than three are required.

They should be such as admit of a ready and accurate comparison with other magnitudes of the same kind. Units of length, mass, and time satisfy this requirement better than any other that can be selected.

They should be capable of use for such comparisons at places and times widely separated; hence they ought to be comparatively easy of re-production and transportation and, as far as human ingenuity can secure, invariable in their magnitude. Units of length, mass, and time satisfy these conditions better than any other.

They should also be so related to each other, as far as such relation

is possible, and the multiples and sub-multiples should be so related to them that units of every possible dimension and character for convenience in the measurement of all measureable things may be derived from them in the simplest manner, and thus be capable of the easiest re-duction and interchange. The units of length, mass, and time, as represented by the centimeter, the gram and the second, fulfill these requirements almost as perfectly as possible. The second falls short of the others because its multiples are not decimally derived, but its use is and has long been so nearly universal that it is not likely to be modified in that respect in the near future. Indeed, a decimal system as applied to time is much less important than when considered in relation to length and mass.

As to the constancy of these units, an arbitrary length and an arbitrary mass are much more capable of accurate reproduction than any natural units of which we now know. When reproduced in considerable numbers and of the best known material, and when widely distributed throughout the civilized world as they now are, under the direction of the International Bureau of Weights and Measures, anything like destruction or loss of the standards must be regarded as well-nigh impossible. Copied in materials of various kinds and preserved under conditions widely varying, it is hardly likely that any secular change in the standards can escape detection, and the accurate determination of the meter in light waves now in progress will afford a valuable check on the constancy of the standard of length.

It thus appears that the metric system with its derived units is to-day by far the most perfect system of metrology ever used by man, and that it lacks little of theoretical perfection. It can hardly be denied that in one or two matters of minor importance it is susceptible of improvement, but it possesses the inestimable and unapproachable advantage of being actually in use by the great majority of civilized nations. Among the innumerable metrological schemes which have made their appearance within the past one hundred years, it is quite possible that some one of them possesses advantages over that based on the meter and the kilogram, and that it would be preferred if we were starting afresh with the whole question. But we are not starting afresh, and it is certainly a cause for sincere and earnest congratulation that a system which is so rapidly advancing in public favor is as nearly absolutely perfect as is this.

Let us turn now to a brief consideration of the origin and present condition of what Lord Kelvin has justly characterized as the brain-wearying, intellect-destroying system of weights and measures in use among English-speaking people.

The fundamental unit of length is the yard, and the unit of mass is the pound. In the time of Edward II it was enacted (A. D. 1324) that 3 barleycorns, round and dry, should make 1 inch and 12 inches make 1 foot. The earliest actual material standard yard of which there is

reliable account dates back to the time of Henry VII (about A. D. 1490). In the Transactions of the Royal Society it is recorded that in 1742 "some curious gentlemen, both of the Royal Society of London and of the Royal Academy of Sciences at Paris, thinking it might be of good use for the better comparing together the success of experiments made in England and in France, proposed some time since that accurate standards of the measures and weights of both nations, carefully examined and made to agree with each other, might be laid up and preserved in the archives both of the Royal Society here and of the Royal Academy of Sciences at Paris," and determined to bring about an exchange of copies of the standards of weight and mass of the respective countries. This led to an examination of the original standards of the exchequer and their copies. It was found that the standard yard then in use was a square rod of brass, of breadth and thickness of about half an inch. The ends were neither exactly flat nor parallel. The standard was an end measure and a matrix was provided for it. Near each end of the yard was stamped a crowned E and it dated from about 1588. Considered as a standard, its character was very inferior, but less so than the old standard of King Henry VII, which was examined at the same time. This is described as an "old eight-sided rod of brass, of the thickness of about half an inch, very coarsely made, and as rudely divided into 3 feet, and one of these feet into inches." This is the standard which dates from A. D. 1490, and is the earliest known material yard.

In 1758, under instruction from a committee appointed by Parliament, John Bird constructed copies of the then existing standards (Elizabethan), one of which, a line measure, was recommended for adoption as the legal standard of length. A copy of this was made by the same artist in 1760, and is known as Bird's standard of 1760, to distinguish it from his first copies made in 1758. Although the subject received much consideration during the next half century, it was not until 1824 that any action was actually taken by Parliament. It follows that up to this date the legal standard of length in Great Britain and her colonies continued to be the very imperfect standard of Elizabeth referred to above. In 1824, however, it was finally enacted that Bird's standard of 1760 should be the fundamental unit of length, and in the same act it was provided that in case of loss it should be reproduced by means of its supposed known ratio to the length of a seconds pendulum at London. In 1834, the Parliament houses, in one of which this standard had been preserved, were destroyed by fire. It is interesting to note that the conflagration was due to the burning of the "tallies" or sticks on which accounts had been kept by means of notches, and in the use of which the Government officials had persisted for many years after it had almost become a lost art elsewhere, thus exhibiting a conservatism characteristic of the whole course of the English Government in reference to metrology and allied sciences.

The legal standard having been destroyed in this manner, it was

found impracticable to reproduce it, as had been intended, by the use of a pendulum, and accordingly a new standard was prepared under the direction of Mr. Sheepshanks from a half dozen excellent copies of the destroyed standard which were available. This was legalized by an act of Parliament in 1855, and is the imperial standard yard of Great Britain to-day. It is a line measure, made of bronze, the total length being 38 inches and the cross section 1 inch square. At the time it was prepared several copies were produced, one of which, known as Bronze No. 11, is in the U. S. office of weights and measures at Washington.

To recur now to standards of length in the United States, it is necessary to repeat the often-published statement that although the Constitution authorizes Congress to establish a system of weights and measures, it has never exercised this authority except in the matter of legalizing the metric system in 1866. The weights and measures in use in the colonies before the Revolution were almost entirely those of Great Britain, and they continued in use without special legalization for a long time after independence was declared. The first Superintendent of the Coast and Geodetic Survey, Mr. Hassler, requiring an accurate standard of length in the operations of that Bureau, obtained from Troughton, of London, in 1814, a brass bar about 82 inches long, 2·5 inches wide, and one-half inch thick. This bar was a direct descendant of the Bird standard of 1760, a number of copies of which had been made by Troughton.

It being necessary for the Executive Departments of the Government to have some standards of weight and measure properly authenticated, for the purpose of levying taxes, duties, etc., this bar, or rather one particular yard of it, from the twenty-seventh to the sixty-third inch, was adopted as the standard of length. It was supposed to be precisely equal to the British standard at a temperature of 62° F. A direct comparison with the copies of the new imperial yard of 1855, however, showed that it was too long at that temperature, and this fact gave rise to the idea which found its way into scientific literature that the English and American yards were different, the latter being the longer. The action taken in the office of weights and measures was simply to change the temperature at which it was a standard, so as to bring it into agreement with the English yard. As a matter of fact its use as a standard was practically discontinued, and the bronze copy of the imperial yard was accepted in its place, together with another copy of this yard made of Low Moor iron and so designated.

It will thus be seen that, as far as the Government is concerned, we have followed the English in the matter of standards of length, and their yard and ours have always been as nearly as practicable identical.

The same is essentially true in regard to the standard of mass. There is an important difference, however, in that Congress did, in 1828, legalize a standard Troy pound for purposes of coinage. This

was a copy of the British Troy pound of 1758, which in 1825 became the imperial standard. It is preserved in the mint at Philadelphia, and is known as the mint pound. The standard avoirdupois pound of the Treasury Department was derived from this Troy pound. Both are very inferior in construction and unsuitable for standards. The present imperial standard of mass of Great Britain is a platinum avoirdupois pound. It was derived from a copy of the standard referred to above, which was lost in the burning of the Parliament houses. As the imperial standard and our own have thus a common ancestor, it is assumed that they are the same.

Besides these units of length and mass the executive officers of the Government adopted two units of volume, the gallon which contains 231 cubic inches and the bushel of 2150·42 cubic inches. They are old English measures and differ very materially from the imperial gallon and bushel now in use in Great Britain.

The above statements apply to what may be known as national or United States standards only in the limited sense that they are the standards of the executive branch of the Government. The whole subject of standards, with the exception as to the metric system already noted was, in the absence of definite action by Congress, left to the law-making authorities of the several States. In view of the great and intelligent interests in this subject exhibited by Washington, Jefferson, Adams, Gallatin, and others of the early statesmen, the omission to legislate in Congress must be attributed largely to the fact of great dissatisfaction with the present system and a hesitancy to recommend any other, however perfect it might seem to be, until it had received the test of actual trial. Realizing the danger which was impending of inharmonious and unscientific legislation by the several States, Congress decided in 1836 to encourage uniformity throughout the country by the distribution among the various State governments of complete sets of weights and measures copied from the standards adopted in the United States office of weights and measures. Some States had already legalized standards differing somewhat from these, but they were soon accepted by all, thus establishing a practically uniform system throughout the country and one in agreement with that adopted by the Government. Strictly speaking, however, each State has its own standards, and they are entirely independent of, although copied from, those in use at Washington. But, as has already been explained, the latter have not themselves been regarded as fundamental standards, being only copies of the imperial standards of Great Britain, in the case of the yard, or descended from the same ancestry, as in the case of the pound, and assumed to be the same. It thus appears that practically, and until a very recent period, our whole system of length and mass measurement was made to depend upon the imperial yard and pound of Great Britain.

The most important legislation upon this subject from the founding

of the Government to the present time is the act of Congress of July 28, 1866, legalizing the metric system of weights and measures throughout the United States. It has not been generally recognized that this system is and has been for more than a quarter of a century the only system whose use is made legal throughout the whole country by act of Congress. Since the passage of this act there has been a decided advance in the use of this system among all civilized nations. This remarkable movement, in which the United States Government, through annual contributions of money and diplomatic negotiations, has had a large part, leaves no room for doubt that in the comparatively near future all mankind will be in the fullest enjoyment of the great boon of a single, universal system of weights and measures, and one as nearly perfect in form and design as could well be expected.

The recognition of this fact has led to recent action on the part of the office of weights and measures at Washington, which is of such importance as to justify the repetition here of the words of Bulletin No. 26, U. S. Coast and Geodetic Survey, April 5, 1893, in which it was first announced.

Fundamental Standards of Length and Mass.

"While the Constitution of the United States authorizes Congress to 'fix the standard of weights and measures,' this power has never been definitely exercised, and but little legislation has been enacted upon the subject. Washington regarded the matter of sufficient importance to justify a special reference to it in his first annual message to Congress (January, 1790), and Jefferson, while Secretary of State, prepared a report at the request of the House of Representatives, in which he proposed (July, 1790) 'to reduce every branch to the decimal ratio already established for coins, and thus bring the calculation of the principal affairs of life within the arithmetic of every man who can multiply and divide.' The consideration of the subject being again urged by Washington, a committee of Congress reported in favor of Jefferson's plan, but no legislation followed. In the meantime the executive branch of the Government found it necessary to procure standards for use in the collection of revenue and other operations in which weights and measures were required, and the Troughton 82-inch brass scale was obtained for the Coast and Geodetic Survey in 1814; a platinum kilogram and meter, by Gallatin, in 1821; and a Troy pound from London in 1827, also by Gallatin. In 1828 the latter was, by act of Congress, made the standard of mass for the mint of the United States, and, although totally unfit for such purpose, it has since remained the standard for coinage purposes.

"In 1830 the Secretary of the Treasury was directed to cause a comparison to be made of the standards of weight and measure used at the principal custom-houses, as a result of which large discrepancies were disclosed in the weights and measures in use. The Treasury Department being obliged to execute the constitutional provision that all duties, imposts, and excises shall be uniform throughout the United States, adopted the Troughton scale as the standard of length; the avoirdupois pound to be derived from the Troy pound of the mint, as the unit of mass. At the same time the Department adopted the wine gallon of 231 cubic inches for liquid measure and the Winchester bushel

of 2150·42 cubic inches for dry measure. In 1836, the Secretary of the Treasury was authorized to cause a complete set of all weights and measures, adopted as standards by the Department for the use of custom-houses and for other purposes, to be delivered to the governor of each State in the Union for the use of the States, respectively, the object being to encourage uniformity of weights and measures throughout the Union. At this time several States had adopted standards differing from those used in the Treasury Department, but after a time these were rejected, and, finally, nearly all the States formally adopted by act of legislature the standards which had been put in their hands by the National Government. Thus a good degree of uniformity was secured, although Congress had not adopted a standard of mass or of length other than for coinage purposes as already described.

"The next, and in many respects the most important, legislation upon the subject was the act of July 28, 1866, making the use of the metric system lawful throughout the United States, and defining the weights and measures in common use in terms of the units of this system. This was the first *general* legislation upon the subject, and the metric system was thus the first and, thus far, the only system made generally legal throughout the country.

"In 1875, an international metric convention was agreed upon by seventeen governments, including the United States, at which it was undertaken to establish and maintain at common expense a permanent international bureau of weights and measures, the first object of which should be the preparation of a new international standard meter and a new international standard kilogram, copies of which should be made for distribution among the contributing governments. Since the organization of the bureau, the United States has regularly contributed to its support, and in 1889 the copies of the new international prototypes were ready for distribution. This was effected by lot, and the United States received meters Nos. 21 and 27, and kilograms Nos. 4 and 20. The meters and kilograms are made from the same material, which is an alloy of platinum with 10 per cent of iridium.

"On January 2, 1890, the seals which had been placed on meter No. 27 and kilogram No. 20, at the International Bureau of Weights and Measures, near Paris, were broken in the Cabinet room of the Executive Mansion by the President of the United States, in the presence of the Secretary of State and the Secretary of the Treasury, together with a number of invited guests. They were thus adopted as the national prototype meter and kilogram.

"The Troughton scale, which in the early part of the century had been tentatively adopted as a standard of length, has long been recognized as quite unsuitable for such use, owing to its faulty construction and the inferiority of its graduation. For many years, in standardizing length measures, recourse to copies of the imperial yard of Great Britain had been necessary, and to the copies of the meter of the archives in the office of weights and measures. The standard of mass originally selected was likewise unfit for use for similar reasons, and had been practically ignored.

"The recent receipt of the very accurate copies of the international metric standards, which are constructed in accord with the most advanced conception of modern metrology, enables comparisons to be made directly with those standards, as the equations of the national prototypes are accurately known. It has seemed, therefore, that greater stability in weights and measures, as well as much higher accuracy in

their comparison, can be secured by accepting the international prototypes as the fundamental standards of length and mass. It was doubtless the intention of Congress that this should be done when the international metric convention was entered into in 1875; otherwise there would be nothing gained from the annual contributions to its support which the Government has constantly made. Such action will also have the great advantage of putting us in direct relation in our weights and measures with all civilized nations, most of which have adopted the metric system for exclusive use. The practical effect upon our customary weights and measures is, of course, nothing. The most careful study of the relation of the yard and the meter has failed, thus far, to show that the relation as defined by Congress in the act of 1866 is in error. The pound as there defined, in its relation to the kilogram, differs from the imperial pound of Great Britain by not more than 1 part in 100,000, an error, if it be so called, which utterly vanishes in comparison with the allowances in all ordinary transactions. Only the most refined scientific research will demand a closer approximation, and in scientific work the kilogram itself is now universally used, both in this country and in England.*

"In view of these facts, and the absence of any material normal standards of customary weights and measures, the office of weights and measures, with the approval of the Secretary of the Treasury, will in the future regard the international prototype meter and kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the act of July 28, 1866. Indeed, this course has been practically forced upon this office for several years, but it is considered desirable to make this formal announcement for the information of all interested in the science of metrology or in measurements of precision.

"T. C. MENDENHALL,
"*Superintendent of Standard Weights and Measures.*

"Approved:
"J. G. CARLISLE,
"*Secretary of the Treasury.*
"APRIL 5, 1893."

As a result of this action, our fundamental units of length and mass are now the new international prototype meter and kilogram preserved by the International Bureau of Weights and Measures, near Paris, and our metrology is in touch with that of the civilized world. This is the second great step toward complete emancipation from the "brain-wearying, intellect-destroying" system with which we have so long been burdened, and let us hope that the time is not far distant when the desire of the author of the Declaration of Independence will be realized

* Reference to the act of 1866 results in the establishment of the following equations:

$$1 \text{ yard} = \frac{3600}{3937} \text{ meter.}$$

$$1 \text{ pound avoirdupois} = \frac{1}{2.2046} \text{ kilo.}$$

A more precise value of the English pound avoirdupois is $\frac{1}{2.20462}$ kilo., differing from the above by about 1 part in 100,000, but the equation established by law is sufficiently accurate for all ordinary conversions.

As already stated, in work of high precision the kilogram is now all but universally used and no conversion is required.

by "bringing the calculation of the principal affairs of life within the arithmetic of every man who can multiply and divide."

None will be more benefited personally by this action, and none can aid more effectually to hasten it, than the distinguished body to which this paper is respectfully submitted. If any argument in its favor were needed, it would be sufficient to cite the example of one department of the great subject of engineering, namely, electrical engineering, which is doubtless represented in some degree in this Congress. But, yesterday a thing unknown, its beautifully simple units of measure and their interrelations are as wings which have enabled it to outstrip those that persist in carrying the dead weight of an unscientific and hopelessly bad system of metrology.

UNITS OF ELECTRICAL MEASURE.*

Within but little more than a decade practical applications of electricity have developed with a rapidity unparallelled in the history of modern industries. Many millions of dollars of capital are now invested in the manufacture of machinery and various devices for the production and consumption of electricity. As it has now become a commodity of trade, its measurement is a question of the highest importance, both to the producer and consumer. Both the nomenclature of electro-technics and the methods and instruments of measure are exceptionally precise and satisfactory, but there has been lacking, up to the present time, the very important and essential element of fixed and invariable units of measure authoritatively adopted. Such units have long been in use among scientific men, but the necessity for the establishment and legalization of practical units for commercial purposes became evident in the beginning of the recent enormous development of the applications of electricity.

To meet this universally recognized want, conferences and congresses of the leading electricians of the world have been held at occasional intervals, the first being the Paris Congress of 1881. These assemblages have been international in their character, for it was wisely determined in the beginning that the new units of measure should be international and, indeed, universal in their application. It was convenient to make them so, and it was important to thus facilitate international interchange of machinery, instruments, etc. The United States was represented by official delegates in the Congress of 1881, and also in subsequent Congresses in 1884.

The difficulty of the material representation of some of the units of measure was so great at the time of holding these Congresses that no satisfactory agreement as to all of them could be arrived at. Some recommendations were made, but they at no time received the unanimous support of those interested and were admitted by all to be tentative in their character. During the past few years the advance of knowl-

* Bulletin No. 30, U. S. Coast and Geodetic Survey.

edge and experience among electricians was such as to indicate that the time was ripe for the general adoption of the principal units of electrical measure. An International Congress of Electricians was arranged for, to meet in Chicago, during the World's Columbian Exposition of 1893. In this Congress the business of defining and naming units of measure was left to what was known as the "Chamber of Delegates," a body composed of those only who had been officially commissioned by their respective governments to act as members of said Chamber. The United States, Great Britain, Germany, and France were each allowed five delegates in the Chamber. Other nations were represented by three, two, and in some cases one. The principal nations of the world were represented by their leading electricians, and the Chamber embraced many of the most distinguished living representatives of physical science.

The delegates representing the United States have reported to the honorable the Secretary of State, under date of November 6, 1893, giving the names and definitions of the units of electrical measure as unanimously recommended by the Chamber in a resolution as follows:

"*Resolved*, That the several governments represented by the delegates of this International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following: As a unit of resistance, the *international ohm*, which is based upon the ohm equal to 10^9 units of resistance of the Centimeter-Gramme-Second system of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14·4521 grammes in mass, of a constant cross-sectional area and of the length of 106.3 centimeters.

"As a unit of current, the *international ampère*, which is one-tenth of the unit of current of the C. G. S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accodrance with accompanying specifications,* deposits silver at the rate of 0·001118 of a gramme per second.

* In the following specification the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time, the time average of the current, or if the current has been kept constant, the current itself can be deduced.

In employing the silver voltameter to measure currents of about 1 ampère, the following arrangements should be adopted:

The kathode on which the silver is to be deposited should take the form of a platinum bowl, not less than 10 centimeters in diameter and from 4 to 5 centimeters in depth.

The anode should be a plate of pure silver some 30 square centimeters in area and 2 or 3 millimeters in thickness.

This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the kathode,

"As a unit of electro-motive force, the *international volt*, which is the electro-motive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampère, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electro-motive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C., and prepared in the manner described in the accompanying specification.*

"As a unit of quantity, the *international coulomb*, which is the quantity of electricity transferred by a current of one international ampère in one second.

"As a unit of capacity, the *international farad*, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

"As a unit of work, the *joule*, which is equal to 10^7 units of work in the C. G. S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampère in an international ohm.

"As a unit of power, the *watt*, which is equal to 10^7 units of power in the C. G. S. system, and which is represented sufficiently well for practical use, by the work done at the rate of one joule per second.

"As the unit of induction, the *henry*, which is the induction in a circuit when the electro-motive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampère per second."

Besides the fact that the Congress in which this important and far-reaching action was taken was held in the United States, our country has been honored by the action of the Chamber of Delegates in placing in the list of the illustrious names which are to be perpetuated in the nomenclature of electricity that of our countryman, Joseph Henry, whose splendid contributions to science, made about sixty years ago, have only in recent years met with full recognition. For these and other reasons it is extremely desirable that our Government should be among the first, if not the first, to adopt the recommendations of the Chamber. To make the use of these units obligatory in all parts of the country will require an act of Congress, but in the absence of that, it is within the power of the Secretary of the Treasury to approve their adoption for use in all Departments of the Government. This indeed is precisely the course long ago followed in reference to the ordinary weights and measures of commerce and trade. Congress has never enacted a

the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

* A committee, consisting of Messrs. Helmholtz, Ayrton, and Carhart, was appointed to prepare specifications for the Clark's cell. Their report has not yet been received.

law fixing the value of their units, but the Secretary of the Treasury was authorized to establish and construct standards for use in the various Departments of the Government. Uniformity has followed on account of the universal adoption of these standards by the several States.

The Government is itself a large consumer of electricity and electrical machinery, and for its own protection it is important that units of measure be adopted. With the approval, therefore, of the honorable the Secretary of the Treasury, the formal adoption by the Office of Standard Weights and Measures of the names and values of units of electrical measure as given above, the same being in accord with the recommendations of the International Congress of Electricians of 1893, has been announced.

PHOTOGRAPHY IN THE COLORS OF NATURE.*

By F. E. Ives.

Heliochromy—meaning sun-coloring—has been settled upon as a name for processes of photography in natural colors, or in the colors of nature. There are two kinds of heliochromic processes. In one, the light itself produces the colors by direct action upon the sensitive plate; in the other, light does not produce colors, but is made to regulate their distribution and combination. Some of the colors of the spectrum were imperfectly re-produced by a process of the first kind nearly thirty years before the discovery of the Daguerreotype process. Seebeck, of Jena, in 1810, found that chloride of silver, after preliminary exposure to white light, is colored a brick-red by prolonged exposure to the red light of the spectrum, and a metalic blue by the blue light. After the discovery of the Daguerreotype process, several experimentalists tried so to modify the preparation of the chloride of silver plates as to make them capable of re-producing all the colors of nature. In a photographic text-book published so long ago as 1853, I find the following statement: "Even the long debated question of the re-production of the natural colors by the agency of light seems on the point of solution. - - - M. Nièpce de St. Victor, from whose well-known character as an experimental philosopher much might be expected, has forwarded to London, as we understand, specimens of proof in which every color is re-produced with a vigor and richness truly wonderful." Similar announcements have been made since that time, but the best results ever actually shown were nothing more than interesting curosities. Dr. W. H. Vogel,† who recently had an opportunity to compare some of the latest and most talked about of these "photographs in natural colors" with the original colored pictures from which they were printed (by contact), says:

"The original is one of those transparent window pictures in bright colors, brought into market by Grimme and Hembel, in Leipsic, as a

* A lecture before the Franklin Institute. From *The British Journal of Photography*, January 23, February 13, 20, 27, 1891; vol. XXXVIII.

† *Anthony's Bulletin*, 1890, p. 325.

substitute for glass painting. It represents a cupid with yellowish-brown hair and wings, and a small blue scarf around the waist, whose ends wave in the wind. He carries an arrow piercing two hearts of ruby color; between the knees he holds a quiver with yellow ornamented opening, and yellow mountings, the lower part of which rests, with the figure, upon an idealistic thistle blossom of red leaves. The stem is of the same color, and the plant shows fresh green leaves. The picture has a pale blue background, and red, green, and yellow ornamentation around the border in very pronounced colors. This border ornamentation affords an excellent means of comparison with the print. The latter, in opposition to the bright original, shows a greenish-grey, partly dark, ground. At first look, one recognizes readily that of all the colors only the red of the original has been distinctly re-produced. But it is not true to nature; it has a copper-red color, and differs decidedly from the vermilion and carmine red of the original. Besides this copper red, only the blue of the scarf and the mountings of the cross-bow and quiver come out a very pale light blue, with no natural resemblance. The black lines of the border decoration appear alongside of this as a violet-black. These are the tones which, to some extent, have a similarity of color, but with the other colors it is not so favorable. The yellow squares and green trapezoids of the border decoration appear neither yellow nor green, but have a greyish-red tone. The blue fields are not blue, but greenish grey, like the ground. It is most singular that several parts are re-produced in red which actually are not red, but brown-yellow, as, for instance, the hair, the wings, the cross-bow, the thistle, etc. The green leaves in the print show no fresh color, and the red leaves of the blossom and the body of cupid show only a pale flesh color. - - - The resemblance of the new photographic pictures to natural colors is, therefore, not very favorable. Only two colors can be recognized distinctly in the copy, of which the red is the best; in a less degree the blue, which is weaker as far as the picture is concerned. The blue in the ornamentation around the border, and all other colors, either have not been re-produced at all, or are entirely unlike the original. - - - If I compare the sample before me with the pictures I have seen in 1867 of Nièpce de St. Victor, Becquerel, and Dr. Zenker, I must confess that those much older productions were richer in color, although the tones deviated likewise considerably from the natural ones."

According to Capt. Abney, the red end of the spectrum produces red by promoting oxidation; the blue end, blue, by its reducing action.* Prof. Mendola † says: "It may at first sight appear improbable that the coincidence between the colors of the spectrum and the colors of the impressed film is a mere accident; but although this is difficult to believe, I venture to think that it is an accidental coincidence and nothing more. - - - In the best specimens of these photo-chromatic spectra that I have seen, the colors were certainly nothing more than approximations to the pure spectrum colors; and even in these spectra some of the colored effect was due to the unaltered ground-color of the film in regions where some particular color had produced no action at all."

*_Anthony's Bulletin_, 1890, p. 307. †_Chemistry of Photography_, p. 324.

The progress by which such imperfect results have been obtained is too slow to be applied sucessfully to camera photography, and the results are not permanent.

In view of all these facts, it would appear that there is no scientific basis for a belief that any material improvement can ever be made in this process, and that all so-called progress along this line is a delusion. It is true that some distinguished photographic writers continue to regard every new modification of this old process, and every new result of experiment with it, as another step towards the photographic re-production of the natural colors; but I have no doubt that if the same writers had lived two hundred years ago they would have regarded the production of new yellow-colored metal alloys as steps toward the transmutation of the baser metals into gold.

In my opinion, the first step toward the solution of this problem was taken by Henry Collen, Queen Victoria's painting master, who, in 1865, invented a plan of composite heliochromy. His plan was based upon a false conception of the nature of color, and means for carrying it out were then unknown; but it was a bright idea, and contained the germ of a successful process. Collen's original communication of his idea appeared in *The British Journal of Photography*, October 27, 1865, and reads as follows:

"It occurred to me this morning that if substances were discovered sensitive only to the primary colors—that is, one substance to each color—it would be possible to obtain photographs with the tints as in nature by some such means as the following:

"Obtain a negative sensitive to the blue rays only; obtain a second negative sensitive to the red rays only, and a third sensitive to the yellow rays only.

"There will thus have been three plates obtained for printing in colors, and each plate having extracted all its own peculiar color from every part of the subject in which it has been combined with the other two colors, and being in a certain degree analogous to the tones used in chromo-lithography. Now, it is evident that if a surface be prepared for a positive picture, sensitive to yellow rays only, and that the two negatives, sensitive only to blue and red, be super imposed either on the other, and be laid on this surface, the action of light will be to give all the yellow existing in the subject, and if this process be repeated on other surfaces sensitive only to red or blue, respectively, there will have been produced three pictures of a colored object, each of which contains a primitive color reflected from that object.

"Now, supposing the first great object achieved, viz., the discovery of substances or preparations, each having sensitiveness to each of the primary colors only, it will not be difficult to imagine that the negatives being received on the surface of a material quite transparent and extremely thin, and that being so obtained are used as above, *i. e.*, each pair of superimposed negatives to obtain the color of the third—that three positives will be obtained, each representing a considerable portion of the form of the object, but only one primary of the decomposed color of it. Now, if these three positives be received on the same kind of material as that used for the negatives and be then laid the one on the other, with true coincidence as to the form, and all laid upon a

white surface, it will not be difficult to imagine that the effect would be not only the representation of the form of the object, but that of its color also in all its compounds.

* * * * * * *

"Although the idea I have endeavored to express in words may be utterly worthless, I am unwilling to let it slip away without notice, as it may on the other hand contain a germ which may grow and bear fruit in due season."

The language of some parts of this communication is ambiguous, but, taken altogether, with due allowance for the writer's unfamiliarity with photographic technology, it clearly amounts to a suggestion to make three photographic negatives of an object—one by the action of red light, one by yellow, one by blue; to print from each pair of these negatives (superposed as one) a transparent positive having the color represented by the third negative, and to superpose on a white surface the three prints thus obtained.

It was not possible to carry out Collen's suggestion at that time, because there was no known process by which plates could be prepared which were sensitive to single colors only, and no photographic plates were sensitive enough to red and yellow to admit of the production of such negatives by exposure through selective color screens. Had it been possible to carry it out, the results must have been very imperfect, not only because the entire procedure is based upon a false and misleading theory of color, but also because superposing two negatives to act as one would double the intensity of such parts as represented white, gray, or pale colored objects, with the result that if the color prints were made to show all the details of the negatives, the finished heliochromes would show all bright colors as if mixed with equal parts of black pigment.

On November 23, 1868, Ducos Duhauron, of Paris, applied for a patent* for a process which differed from Collen's only in the manner of carrying out the same idea. Like Collen, he assumed that the spectrum is made up of three primary color rays and mixtures thereof. He said, "My procedure rests on the principle that the simple colors are limited to three—the red, the yellow, and the blue—the combination of which in divers proportions produces the infinite variety of shades in nature." Like Collen, he expected to solve the problem by superposing red, yellow, and blue prints taken from negatives made by yellow and blue, red and blue, and yellow and red light. But, instead of using plates sensitive to single colors only, he proposed to use plates sensitive to all colors, and to prevent the action of color rays not wanted by filtering them out with color screens placed in front of the photographic objective or sensitive plate; and, instead of superposing two negatives to act as one, from which to make the color prints, he proposed to make two colors (two-thirds of the spectrum rays) act to produce each negative, which

*Class XVII, sec. 3, serial No. 83061.

amounts to the same thing, and would not obviate the defect I have mentioned as resulting from the doubling of intensity on uncolored objects. He proposed to make one negative through an "orange" screen, calculated to absorb the blue light and transmit the red and yellow; one through a "violet" screen, calculated to absorb the yellow light and transmit the blue and red; one through a "green" screen, calculated to absorb the red light and transmit the yellow and blue.

It was no more possible to carry out this idea in Duhauron's way in 1868, than to carry it out in Collen's way in 1865. It is true, Duhauron tried to carry it out, and showed, specimens of work, but the red and yellow rays did not act on his sensitive plates,* and he admitted, in a communication to the French Photographic Society,† that "the production of good results will - - - involve the manufacture of compounds which have not yet been created."

Soon after Duhauron showed his first specimens, Charles Cros, of Paris, published another modification of Collen's plan.‡ Like Collen, Cros proposed to make one negative by the action of red light, one by yellow, and one by blue, but by exposing the sensitive plates through red, yellow, and blue screens instead of employing plates sensitive to single colors only. Instead of superposing each pair of these negatives to make each color print, he proposed to make a green print from the negative made by red light, a violet print from the negative made by yellow light, and an orange print from the negative made by the blue light. He also suggested that ordinary positive prints made from these negatives might be illuminated each by the kind of light which it represented, and the three combined by the aid of suitable optical devices so as to form a single picture, showing all the colors. Cros's plan, although it could not succeed, because based upon the same false and misleading theory as that accepted by Collen and Duhauron, nevertheless possessed one important advantage over the preceding methods: it was free from the defect of doubling intensity on those parts of the negatives representing pale or uncolored objects. But this advantage would be lost again in the production of green, violet, and orange colored prints, which will combine to reproduce yellows and blues only with a degree of degradation comparable to that produced by Duhauron's method.

On December 3, 1869, M. Poirée, of Paris, in a communication to the Photographic Society of France,§ expressed doubts concerning the correctness of Duhauron's and Cros's theories, and suggested that better results might be had by making a greater number of negatives—a separate negative for each spectrum region. He said, "The process which seems likely to succeed best is that in which the colors are analyzed by

* Yellow pigments were photographed by the green rays which they reflected.

† *Photographic News*, 1869, p. 319.

‡ Described in *Photographic News*, October 8, 1869, p. 483.

§ *The British Journal of Photography*, 1870, p. 26.

isolating successively each ray, or at least the rays of the same shade. - - - This analysis is difficult to make with colored glasses; it might be done, as by Newton, by monochromatic lighting and successive exposures to simple rays of the same shade. - - - The synthesis is made by means of black positive images and rays of the same nature as those which produced the corresponding negatives. - - - It will then only be necessary to place one above another the colored images so obtained, so as to form one virtually and really. It will be identical with the model, because it will be formed by the same rays, in the same relation of intensity." This also could not then be carried out because no photographic sensitive plates were sufficiently sensitive to yellow, orange, and red spectrum rays.

In 1873, Dr. H. W. Vogel discovered that bromide of silver can be made sensitive to the less refrangible spectrum rays by treatment with certain dyes, and the subsequent discovery of other and better color sensitisers supplied the means for carrying out either Collen's or Poirée's idea.

Duhauron, one of the first to avail himself of these discoveries, made some practical progress, and, in 1876, abandoned Brewster's color theory and patented a modified process,* based upon the observation that, while there appeared to be *seven* "principal" spectrum colors, three coloring substances would "serve to express them." The coloring substances he named for this purpose are blue, carmine, and yellow, and he decided that, in order to make such a process reproduce the colors of nature, the negatives should be made by the action of orange, green, and violet spectrum rays, which are complementary to the coloring substances. Some persons have thought that he had the idea of making negatives to represent primary color sensations, but this supposition is negatived, not only by the absence of any declaration to that effect, but also by the fact that orange does not represent a primary color sensation, either in fact or according to any theory recorded in the textbooks, and the violet rays are not the ones which most powerfully excite the blue (violet) sensation. The plan was also utterly indefinite as regards the relative effect of intermediate spectrum rays, and Duhauron himself, owing to the fact that he never tried the method upon the spectrum, had no accurate knowledge of its capabilities. In his latest and perfected process (1878) † he employed no plate sensitive to either red or orange light. One negative was made chiefly by yellow light, another by green, and the third chiefly by violet and invisible ultra-violet rays.

Albert, of Munich, also took advantage of the discovery of color sensitisers to try to carry out Collen's principle according to Duhau-

* British patent, July 22, 1876, No. 2973.

† "Traité Pratique de Photographie des Couleurs," Paris, 1878, *Photographic News*, 1878, p. 115.

ron's original plan. He was the first to make the color prints by the collotype process, which led to the use of the term "chromo-collotype."

In 1879, Cros* abandoned the idea that red, yellow, and blue are primary spectrum colors, but still held that there are three primary colors and mixtures thereof, and that these primary colors are orange, green, and violet. Like Duhauron, he decided to make negatives by light of these colors and prints in blue, red, and yellow.

In 1884, Dr. F. Stolze, of Berlin, made a series of investigations and tried to solve the problem by devising a procedure more in accordance with Young's theory of color.† He said: "Although the colors correspond with certain external processes in nature, there is also no doubt that color as such is nothing objective, but a subjective sensation, based upon the peculiar irritation of the visual nerves by those external proceedings. We can, therefore, only hope to produce a picture in natural colors when we are enabled to reproduce upon the same the proceedings which furnish to us the color impression. The general idea of all colors being based upon the three principal colors, red, yellow, and blue, is an erroneous one. Thomas Young - - - assumes that there are three kinds of nerve fibers sensible to red, green, and violet. Objective homogenous light excites all three; but with red the first is excited strongly, the second and third weakly; with blue, the second and third moderately strong, the first weakly; with violet, finally, the third strongly, and the first and second weakly. If all three kinds of nerve fibers are equally strongly excited the impression of white light will take place."

This theory in accordance with which Dr. Stolze tried to devise a theoretical solution of the problem is only partly correct, measurements by Clerk Maxwell and others having shown that the red sensation is neither affected by blue-green, blue, or violet rays, nor the blue (violet) sensation by red, orange, or yellow rays, nor the green sensation by red or violet rays. Neither is it the red rays that chiefly excite the red sensation, nor the violet rays that chiefly excite the blue (violet) sensation.

As a result of elaborate calculations, which, it must be said, could just as well have been made without any reference to Young's theory of color, Dr. Stolze came to the conclusion that if three suitable selective color screens were used in connection with color sensitive plates three negatives of the spectrum might be obtained, from which prints in cyan blue, carmine, and yellow, if superposed, would reproduce the color effect of the spectrum. He did not show how to make selective color screens calculated to secure the right kind of negatives to carry out this idea, nor state what should be the form of the intensity curves in such negatives of the spectrum. He merely gave a table, showing

* Bulletin of the French Photographic Society, 1879, p. 23.

† *Anthony's Photographic Bulletin*, 1886, pp. 516, 555, 588, 647, 678.

on what parts of the spectrum each negative should fix color, and said: "If successful - - - in selecting the color screens in such a manner that they will let the color pass through which are called for in this table, one will indeed be able to reproduce a pure spectrum in this way." By further calculations he was able to show that this plan, even if successfully carried out, would not insure the correct reproduction of mixed colors. He said: "All pure saturated spectrum colors will also be obtained quite satisfactorily in the reproduction, but the mixed ones only partly." "Oftentimes they have to become more or less impure." "But the clearest lights and a number of mixed colors appear very unsatisfactory." He added: "The intelligent support of the artist can lend improvement," and recommended also the production of a fourth (ordinary) negative, to be used in combination with the others, to modify the effect, especially in high lights.

This plan can not be said to definitely represent the application of Young's theory of color, but it may be practically better than anything that that theory would indicate if we leave out of account the suggestion of a fourth negative.

In 1885, Dr. Vogel published a plan, which is a modification of Poirée's.* Like Poirée, he proposed to make a separate negative for each spectrum region; but, instead of using plates sensitive to all colors and exposing through selective color screens, or illuminating the subject by monochromatic lights, Vogel proposed to sensitise plates specially for each spectrum region, which would amount to the same thing, and instead of projecting the pictures with colored lights, he proposed to make as many pigment prints as negatives, each in a color complementary to the light which acted to produce the respective negative, and to superpose them as in the Collen method.

There are no known dyes with which this plan could be carried out; and even if there were, it is, I believe, too complicated to be practicable.

In February, 1888,† I demonstrated a procedure based upon the assumption that although there are more than three or five or seven primary spectrum colors, all of them—and in fact all the colors of nature—can be counterfeited to the eye by three type colors and mixtures thereof. This was not a new observation, and my plan did not differ very materially from that of Dr. Stolze, minus the complication of a fourth negative, except that it was more definite; and instead of merely publishing it as a suggestion, I found means to carry it out, and made a practical demonstration of it. I proved the process by photographing the spectrum itself, employing compound color screens carefully adjusted to secure definite intensity curves in the spectrum negatives, so that they would make color prints which counterfeited the color effect of the spectrum when superposed. The adjustment of plates

* *Annalen der Physik* (n. s.), vol. XXVII, p. 130; *Photographic News*, 1887, p. 568.

† *Journal of the Franklin Institute*, 125, 345.

and screens to secure *spectrum negatives having definite intensity curves*, which I believe had never before been done, made all the difference between an indefinite and uncertain method and one definite and precise.

Promising results were obtained by this process, but I soon came to the conclusion, already reached by Dr. Stolze, that a process might re produce the color effect of the spectrum, and yet not be capable of re-producing perfectly the compound colors. The solution of the problem was incomplete until I discovered a new principle, according to which such a procedure can be made to re-produce not only the spectrum, but also all the hues of nature.

This new principle, first stated by me in a communication to this institution on November 21, 1888,* is that of making sets of negatives by the action of light rays in proportion as they excite primary color sensations, and images or prints from such negatives with colors that represent primary color sensations.

In order to understand this principle, I must explain that although the spectrum is not made up of three kinds of color rays and mixtures thereof, the eye is only capable of three primary color sensations, a distinction of the utmost importance, for the reason that the spectrum rays, which most powerfully excite a primary color sensation, are not the ones which represent the character of that sensation. The primary sensations are red, green, and blue (violet); but it is not the red, green, and violet spectrum rays that most powerfully excite these sensations. According to Clerk Maxwell, the orange spectrum rays excite the red sensation more strongly than the brightest red rays, but also excite the green sensation; the greenish-yellow rays excite the green sensation more strongly than the purest green rays, but also excite the red sensation; the yellow rays excite the red sensation as intensely as the brightest red rays and the green sensation as intensely as the purest green rays.

The carrying out of my new principle, according to Maxwell's measurements, therefore, involves the production of one negative by the joint action of the red, orange, yellow, and yellow-green rays, in definite proportions, to represent the red sensation; one by the joint action of the orange, yellow, green, and green-blue rays, in definite proportions, to represent the green sensation; and one by the joint action of the blue-green, blue, and violet rays, in definite proportions, to represent the blue sensation.

Negatives of the required character can be made by exposing a cyanine-stained gelatine-bromide plate through a double screen of chrysoidine-orange and aniline-yellow of suitable intensity for the red sensation, a cyanine-erythrosine gelatine-bromide plate through a screen of aniline-yellow of suitable intensity for the green sensation, and an ordinary gelatine-bromide plate through a double screen of crysophenine-

* *Journal of the Franklin Institute*, January, 1889.

yellow and R R methyl-violet for the blue sensation. The plates and screens are correct when they will secure negatives of the spectrum showing intensity curves substantially like the curves in Maxwell's diagram. The negatives can also be made on certain makes of ordinary commercial gelatine bromide plates of the most rapid kind, by the use of quite different color screens for the first two, but only with exposures of from five to fifteen minutes on well-lighted landscapes, aperture of objective, *f*-12.

In photographing objects in a changing light—landscapes, for instance,—it is important that the three sensitive plates be exposed simultaneously; and in order to accomplish this, I devise a triple camera, having three lenses so arranged in connection with reflectors as to bring all the points of view within a one-inch circle. With this camera, the production of sets of negatives of the required character is a simple and easy matter, it being only necessary to insert the plates, raise the flap until the exposure is made, take the plates out again, and, when convenient, to develop them together in the ordinary way.

There are two ways of making the heliochromic pictures from these negatives. The first method does not produce a permanent picture, but a screen projection.

Lantern slides made from the heliochromic negatives and exactly reversing their light and shade must also represent the effect of the object upon the respective color sensations. One lantern positive, when seen by transparency in red light, re produces the effect of the object upon the primary red sensation. Another, viewed in the same manner by green light, re-produces the effect of the object upon the green sensation. The third, viewed by blue-violet light, re-produces the effect upon the blue sensation. Evidently the combination of these three images into one must form a re-production of the object as seen by the eye, correct in form, color, and light, and shade. Such a combination is effected by projecting the three pictures with a triple optical lantern, so that they exactly coincide upon the screen. The result is what we have been led to expect.

We have here a true solution of the problem of re-producing the colors of nature in a screen picture, dating from November, 1888. Previous to the publication of my new principle it was assumed by Cros, Poirée, and others, that if the projection method were employed each picture should be projected by the same kind of rays as those which acted to produce it. In my method, as I have already stated, a picture made by the joint action of red, orange, yellow, and yellow-green rays, but chiefly by orange, instead of being projected by a similar mixture of spectrum rays, is projected by red rays only. Similarly, the picture made by orange, yellow, green, and green-blue rays is projected by green rays only, and that made by blue-green, blue, and violet rays, by blue-violet rays only.

Dr. Stolze, who was one of the first to recognize the genuineness of this solution of the problem, doubted if, even in theory, color prints

from the same kind of negatives could be made to furnish such a perfect solution. A year ago I also believed that there were theoretical difficulties in the way of realizing a perfect process with color prints. Only recently have I succeeded in showing what relation the colors of the prints must bear to the colors of light used in projection, in order to perform exactly the same function and, under like conditions of illumination, secure equally perfect fulfillment of theoretical requirements.

In the projecting method, we build up the luminous image by adding light to light. White light is produced by the mixture of the three colored lights used for projection, and black by their suppression But when we carry out the process to produce permanent pictures, the paper which may form the basis of the picture is itself white, and it is the shadows that are built up by the super-position of color prints.

Nevertheless, the color print has exactly the same function to perform as the lantern positive, *i. e.*, to absorb and suppress by its shading, light affecting one primary color sensation. If we remove our three positives from the lantern, the screen is evenly illuminated with white light. If we then replace the one representing the green sensation, its shadows will absorb the green light with the result that the screen bears a picture in the complementary color, pink, on a white ground. In the color-print method we commence with a white surface which corresponds to the fully illuminated screen, and the shadows of the color print representing the green sensation, when laid upon this surface, absorb the same kind of rays as the shadows of the positive in the lantern, and with the same result, a pink monochrome picture on a white ground. Superposing the other two color prints upon the first one on paper is like inserting the other two positives in the lantern. This explains why the primary sensations are represented by prints having shades of the complementary (absorbing) color. It is the lights and not the shades of the color prints that represent the effect upon the respective primary color sensation. It is only necessary to use dyes that completely absorb red light but neither green nor blue-violet for the print representing the red sensation, green but neither red nor blue-violet for the green sensation, blue-violet but neither red nor green for the blue sensation, in order to obtain from my negatives a color print heliochrome that exactly fulfills all theoretical requirements, provided that it be examined in the same kind of white light that we obtain in the screen projections by mixing red, green, and blue-violet rays. The dyes mentioned by me in my paper of November 21, 1888 (Prussian blue, aniline-magenta, and aniline-yellow), fulfill this requirement, and color-print heliochromes made therewith according to my instructions must therefore re-produce all the colors of nature under the conditions of illumination just stated.

In order to obtain colors that would appear of exactly the right kind and shade in ordinary white light, it would be necessary to use dyes each of which completely absorbed all light affecting the color sensation which it represented, but no other. The colors would then be correct in ordinary white light, but would appear too dark, relatively,

to the white ground. In order to obtain colors that would appear brighter in ordinary white light, dyes may be used which completely absorb only rays that excite chiefly single primary sensations and other rays in due proportion. The dyes proposed by me also fulfil this requirement, so that even in ordinary white light the degradation of a color is insignificant except in the greens, where it is noticeable.

I have seen some of the results produced by the older process of composite helichromy, and others who have also seen them will I am sure bear me out when I say that the colors have invariably been not only untrue, but either very dull or else flat and patchy and wanting in the delicate details and gradations of light and shade which characterize good monochrome photographs. All that showed bright colors resembled nothing so much as cheap chromos. In the composite heliochromes by my process, which I show to-night, the colors are, as you can see, as perfect in detail and gradation as the monochrome shades of an ordinary photograph. - - -

In photo-chromy it is only necessary for the photographer to make one negative of the object to be re-produced, and this negative contains a register of form and light and shade only. Composite heliochromy can not be carried out with less than three negatives, which must contain a register not only of form and light and shade, but of color also. In photochromy an artist is employed to regulate the distribution of colors, according to his taste or judgment; in composite heliochromy it is the light itself which regulates their distribution and combination, automatically, according to fixed and true scientific principles. Photochromy is an art; composite heliochromy a science. - - -

In conclusion I will say that in order to carry out the process in strict accordance with the theoretical requirements, means must be employed not only to secure three negatives and three prints, each of which is correct by itself, but each must bear also a certain definite relation to the others. A very little over or under exposure of any one color print, or a very little too much or too little of the color stuff in the film, will change the shade of delicate colors. Fortunately, there is a simple optical test by which such a defect can be detected without reference to, or knowledge of, the colors of the object photographed; but at present it is difficult to secure such harmony of parts when but little time can be spared to devote to the operation of the process. Composite heliochromy must always remain a comparatively costly process when carried out in a manner calculated to yield the finest results, and can most profitably be brought before the public in the form of optical lantern lecture illustrations, not with the triple lantern, but with transparent colorprint helio-chromes mounted as lantern slides.

PHOTOGRAPHS IN NATURAL COLORS, BY THE PROCESS OF L. LUMIÈRE.*

By LEON WARNERKE.

About two years ago Prof. Lippmann, of the Sorbonne, at Paris, succeeded in producing photographically a colored image of the solar spectrum, based on the well-known principles of interference. He used for that purpose a plate coated with an albumen, collodion, or gelatin sensitive film. This sensitive film was during exposure brought into contact with metallic mercury, the image of the spectrum being projected on the film, through its glass support. The light, after penetrating through the thickness of the film, was reflected back from the surface of the mercury, the direct light waves encountering the waves of reflected light, producing the phenomenon of interference in the thickness of the film. The waves of light propagating in opposite directions cause the vibrations at certain intervals to be neutralized, while at others they are intensified. If such a plate could be developed, fixed, and dissected, we should find it to consist of strata of the black deposit of silver, produced by the developer in the parts corresponding with the maximum of light succeeded by transparent strata, corresponding to the minimum of light, where the developer had no action. The distance between the strata is equal to half the wave length, which is 600 ten-thousandths of a millimeter for red light, 583 for orange, 551 for yellow, 475 for blue, and 423 for violet. In a film of $\frac{1}{20}$ millimeter thickness there will be about 200 such strata. It is evident that on examining such a plate by reflected light we should observe the colors, because it is formed of a series of films of the thickness requisite to produce color sensations.

Subsequent experiments proved that by using a gelatin film, sensitised with a chromium salt, a similar result is obtained, the action of interference producing strata of soluble and insoluble gelatin.

The exposure of the plates produced by Lippmann was very long, and, owing to the variation of sensitiveness of different rays of the spectrum, necessitated the masking of the portions exposed to the more actinic rays while the others are exposed. L. Lumière succeeded in producing colored images in one operation, and in last May, in a paper

* Read before the Photographic Society of Great Britain, October 11, 1893 (*Journal and Transactions of Phot. Soc. G. B.*, Oct. 28, 1893; vol. XVIII, pp. 52-54).

read before the Paris Académie de Science, gave full particulars of the process, as follows:

To prepare the emulsion the following solutions are made:

		Parts.
A	Distilled water	400
	Gelatin	20
B	Distilled water	25
	Potassium bromide	2·3
C	Distilled water	25
	Silver nitrate	3

One-half of A is added to B and the other half to C. These two solutions are mixed by adding the silver to the bromide. A suitable sensitiser is added, such as cyanine, methyl violet, erythrosine, etc., and after filtration plates are coated on a tourniquet at a temperature of 40° C.

When the emulsion is set the plate is immersed in alcohol for a very short time, and washed in a continuous stream of water. The film being very thin the washing is soon effected. This emulsion should not be washed in bulk, lest coarseness of the particles of silver produced by re-heating results, and in order to leave the films as transparent as possible; for the same reason an excess of bromide is to be avoided. The plates are dried, and just before use are immersed for 2 minutes in:

	Parts.
Water	200
Silver nitrate	1
Acetic acid	1

This bath helps to produce brilliancy of the image, and to increase the sensitiveness. But the plates cannot then be kept long, because the sensitive surface soon deteriorates. When the plate is dry, it is ready for exposure *à la* Lippmann, viz, with a reflecting surface next to the film.

For the developer the following solutions are made:

		Parts.		Parts.
I	Water	100	Sol. I	10
	Pyrogallic acid	1	Sol. II	15
II	Water	100	Sol. III	5
	Potassium bromide	10	Water	70
III	Ammonia D.			
	0·960 diluted to 18°			

The degree of concentration of the ammonia has a great influence on the result, even a slight alteration destroying the brilliancy of the colors. For fixing, the plate after washing is immersed for from 10 to 15 seconds in a 5 per cent. solution of potassium cyanide, washed and dried.

In order to lessen the action of the ultra-violet, violet, and blue rays, a parallel faced bath of Victoria yellow, uranin or primuline is used in the camera.

ELECTRIC-SPARK PHOTOGRAPHS OF FLYING BULLETS.*

By C. V. Boys, F. R. S.

When I was honored by the invitation to deliver this lecture I felt some doubt as to my ability to find a subject which should be suitable, for there is a prevailing idea that, in addressing the operative classes, it is necessary to speak only of some practical subject which bears immediately upon the most important industry of the place in which the lecture is being delivered; but it seems to me that this is a polite suggestion that the audience are unable to be interested by any subject except that particular one which occupies them daily. Now, though I am a comparative stranger in Scotland, I have heard quite enough and I know quite enough, of the superiority of the education of you, who have the good fortune to live in this the most beautiful half of Great Britain, to be aware that, as is the case with all highly-educated men, you are able to take a keen and genuine interest in many subjects, and that I had better choose one to which I have specially devoted myself, if I do not wish to expose myself to the risk of being corrected. I will ask you therefore in imagination, to leave your daily occupation and come with me into the physical laboratory, where, by the exercise of the art of the experimentalist, problems which might seem to be impossible are continually being solved. I wish as an experimentalist to present to you an example of experimental inquiry.

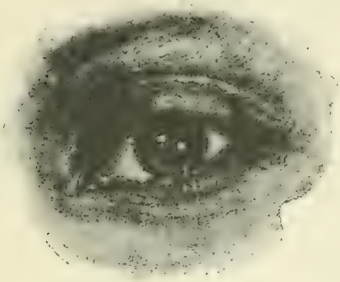
Let us suppose that for some reason we wish to examine carefully and accurately some moving object travelling, if you will, at so great a speed that, observed in the ordinary way, it appears as a mere blur, or perhaps at a speed so tremendous that it can not be seen at all. In such a case, in order to get a clear view of the moving body we may either look through an aperture which is only opened for a moment as the body passes by, or we may suddenly illuminate the object by a flash of light when it is in a position in which it may be seen. If in either of these cases the hole is open, or the illumination lasts so short a time that the object has no time to move appreciably while it is in

* Lecture delivered at the Edinburgh meeting of the British Association for the Advancement Science, August, 1892. (From *Nature*, March 2 and 9, 1893, vol. XLVII, pp. 415–421, 440–446.)

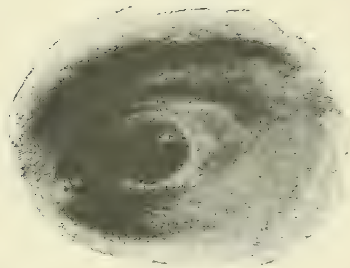
this way brought into view, we get what may in ordinary language be called an instantaneous impression and the object appears clear, sharp, and at rest. In the same way if we wish, with the object of obtaining a permanent record, to photograph a moving body we must either allow the eye of the camera to see through a hole for a moment, *i. e.*, we must use a rapid shutter—and many such are well known—or we must, keeping the photographic plate exposed and the object in the dark, make a flash of light at the right time. As before, if the shutter is open or the flash lasts so short a time that the object can not move appreciably in the time, then, if any impression is left at all, it will be sharp, clear, and the same as if the body were at rest. The first method, that of the shutter, I do not intend to speak about to-night, but as, owing to the kindness of Mr. F. J. Smith, I have with me the most beautiful example that I have seen of what can be done by this method, I thought perhaps I should do well to show it. Mr. Smith was in an express train near Taunton, travelling at forty miles an hour, and when another express was coming up in the opposite direction at sixty miles an hour, *i. e.*, approaching him at one hundred miles an hour, he aimed his camera at it and let a shutter of his own construction open and shut so quickly that the approaching train was photographed sharply. There is a special interest about this photograph; it shows one of the now extinct broad-gauge engines on the road. However, this is an example of the method which we shall not consider this evening.* For our purpose we require what is called instantaneous illumination—a flash of light. It is of course obvious that it depends entirely upon the speed of the object and the sharpness required, whether any particular flash is instantaneous enough. No flash is absolutely instantaneous, though some may last a very short time.

For instance, a flash of burning magnesium powder lasts so short a time that it may be used for the purpose of portraiture, and while it lasts even the eye itself has no time to change. Pl. II, fig. 1, represents a photograph of the eye of Mr. Colebrook after he had been some minutes in a dark room, taken by the magnesium flash; the same eye taken in daylight appears in Pl. II, fig. 2. The pupil is seen fully dilated and the eyelid has not had time to come down, and so we might reasonably say that the flash was instantaneous; it was for the purpose practically instantaneous. Yet when I make this large clock face, 4 feet across, revolve at so moderate a speed that the periphery is only travelling at 40 miles an hour and illuminate it by a magnesium flash you see no figures or marks at all, only a blur. Thus the magnesium flash, which for one purpose is practically instantaneous, is, tested in this simple way, found to last a long time. Let me now, following Lord Rayleigh, contrast the effect of the magnesium flash with that of a powerful electric spark. At each spark the clock face appears brilliantly illuminated

* I have heard that a cannon ball has been photographed by means of a rapid shutter, but I have no direct information on the subject.

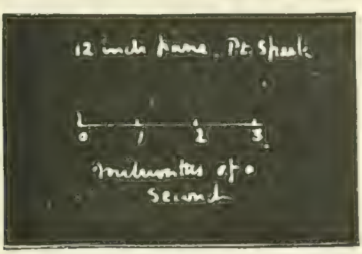


1. Eye by magnesium flash.



2. Eye by daylight.

3



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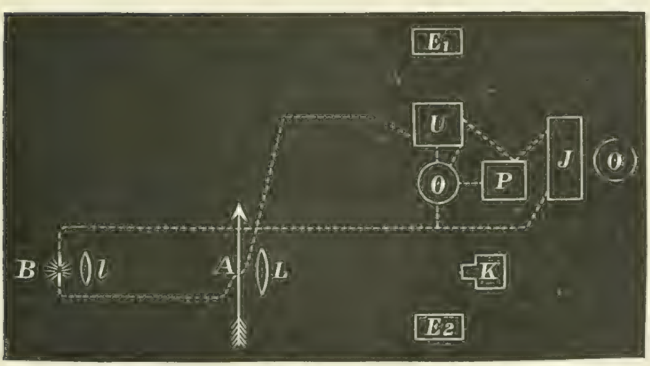

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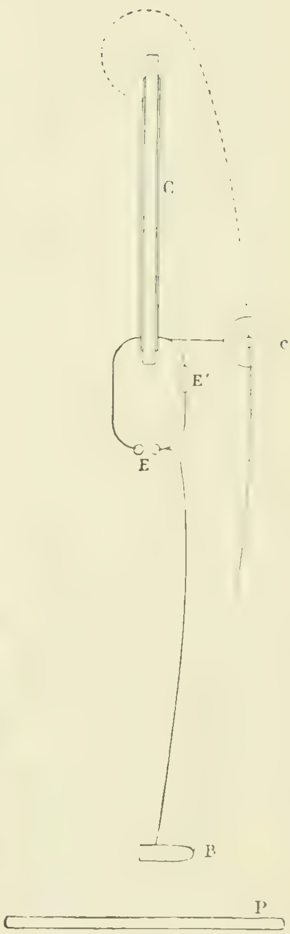


6

PHOTOGRAPHY OF FLYING BULLETS.

(Reprinted from "Nature," by permission of Prof. C. V. Boys.)

and absolutely at rest and clear, and if it were not that I could at once illuminate it by ordinary light it would be difficult to believe that it was still in motion.

The electric spark has been often used to produce a flash by means of which phenomena have been observed which we ordinarily can not see. For instance, Mr. Worthington has in this way seen and drawn the exact form of the splash produced by a falling drop of liquid.

Mr. Chichester Bell, Lord Rayleigh, Mr. F. J. Smith, and others have used the illumination produced by an electric spark to photograph phenomena which they were investigating. I am able to show one of Lord Rayleigh's, a breaking soap bubble, in which the retreating edge, travelling something like 30 miles an hour, is seen with all the accuracy and sharpness that is possible with a stationary object. Mr. F. J. Smith has extended the use of sparks for the purpose of physiological inquiry, taking a row of photographs on a moving plate at intervals that can be arranged to suit the subject, and is thus putting in the hands of the much-abused experimental physiologist a very powerful weapon of research. I had hoped to show one of these series of an untechnical character, to wit, a series taken of a cat held by its four legs in an inverted position and allowed to drop. The cat, as every one is aware, seems to do that which is known to be dynamically impossible, namely, on being dropped upside down to turn round after being let go and to come down the right way up. The process can be followed by means of one of Mr. Smith's multiple spark photographs. However, his cats do not seem to like the experiments, and he has in consequence had so much trouble with them that his results, while they are of interest, are not, up to the present, suitable for exhibition.

Let me now return to single spark photographs. We have seen that the magnesium flash, which for the purpose of portraiture is practically instantaneous, yet fails to appear so when so moderate a speed as 40 miles an hour (and indeed a far lower speed) is used for the purpose of examining it. Is anything of the kind true in the case of the electric spark? Will the spark, by which we saw the clock-face absolutely sharp, after all fail to give a sharp view when tested by a much higher speed? I have taken such a spark and attempted (though I knew what the result would be) to photograph by its light the bullet of a magazine rifle passing by at the rate of about 2,100 feet a second, or, what is the same thing, at about 1,400 miles an hour; the result (Pl. II, fig. 3) shows not a clear, sharp bullet, but a blur; the spark lasted so long a time that this bullet was actually able to travel half an inch or so while the illumination lasted. Thus we see, that if we wish to examine bullets, etc., in their flight, any electric spark will not necessarily do. We shall have to get a spark which while it gives enough light to act on the plate yet lasts so short a time that even a rifle bullet can not move an appreciable distance during the time that it is in existence.

A knowledge of electrical principles enables one to modify the electrical apparatus employed to make this spark in such a manner that its duration may be greatly reduced without, at the same time, a very great sacrifice of light; but while this may be done it is important to be able to observe how long the spark actually lasts when made by apparatus altered little by little in the proper manner. The desired information is at once given by the revolving mirror. For instance, every one is aware how, by the turn of the wrist, one may reflect a beam of sunlight from a piece of looking glass so as to travel up the street at a most tremendous velocity; but suppose that, instead of being moved by a mere turn of the wrist, the mirror is made to rotate on an axle by mechanical means at an enormous speed; then, just as the rotation is more rapid, so will the beam of light travel at a higher speed. In the particular case that I am now going to bring before your notice, a small mirror of hardened steel was made by Mr. Colebrook, the mechanical assistant in the physical laboratory at South Kensington, mounted so beautifully that it would run at the enormous speed of 1,000 turns a second (not 1,000 a minute) without giving any trouble. The light from the spark was focused by the mirror upon the photographic plate. Now, if the light were really instantaneous, the image would be as clear and sharp as if the mirror were at rest; if, on the other hand, it lasted long enough for the image to be carried an appreciable distance, then the photograph would show a band of light drawn out to this distance. The mirror is now placed on the front of the platform, and a beam of electric light is focused by it upon the screen, from which it is distant about 20 feet. Now that I turn the mirror slowly you see the spot of light drawn out into a band reaching across the screen, and this is described over and over again as the mirror revolves. Let us suppose that the mirror is revolving once a second, then it is easy to show that the spot of light is travelling at about 250 feet a second. It is not difficult, therefore, to see that if the mirror is revolving 1,000 times as fast the spot of light will traverse the screen 1,000 times as fast also, *i. e.*, about 250,000 feet a second, or 160,000 miles an hour, a speed which is 200 times as great as that of a Martini-Henry bullet, while such a bullet only travels 14 times as fast as an express train. You will see, then, that it is not difficult to observe how long a spark lasts when its image can be whirled along at such a speed as this. I have now started the electromotor, and the mirror is turning more and more rapidly. Now it gives a musical note of the same pitch as that given by the tuning fork I am bowing; it is therefore turning 512 times a second. It is now giving a higher note, *i. e.*, it is turning faster and faster, until at last it gives the octave, at which time it is turning 1,028 turns a second. The band of light on the screen is produced by a spot now travelling at a still higher speed than that which I have just mentioned.

I had hoped to have shown with this apparatus the actual experiment of drawing out the apparently instantaneous flash of an electric

spark into a band of light, but I found that while it was easy to show the experiment in a small room, the amount of light was not sufficient to be seen in a great room like this. I must therefore be content to show one or two of the photographs which were taken lately in the physical laboratory at South Kensington by two of the students, Mr. Edser and Mr. Stansfield, whom I now take the opportunity of thanking. The next slide shows the drawn-out band of a particular spark made between magnesium terminals by the discharge of a condenser of $2\frac{1}{2}$ square feet of window-glass, the spark being $\frac{1}{8}$ inch long. Below the drawn-out band I have drawn a scale of millionths of a second. If the spark had been instantaneous it would have appeared as a fine vertical line. This line however has been drawn sideways to an extent depending on the duration of the spark. The spark, except at the ends, is extinct in rather less than one-millionth of a second, but the ends remain alight like two stars, being drawn out in consequence into two lines, which have lasted, as measured by the scale, as long as six or seven millionths of a second. Such a light is, therefore, seen to last when tested with this very powerful instrument so long that it seems absurd to call it instantaneous. It lasts too long for the purpose of bullet photography. In order to get sparks of shorter duration it is necessary to abolish the metal magnesium, in spite of the brilliant photographic effect of the two ends of the spark between knobs of this material; it is well to avoid all easily volatile metals, such as brass, because of the zinc that it contains, and instead to employ beads of copper or of platinum. In the second place, the duration of the spark proper, which in the last case was nearly a millionth of a second, can be reduced by (1) reducing the size of the condenser, but one must not go too far, as the light is reduced also; (2) by replacing any wire through which the discharge may have taken place by broad bands of copper as short as possible; this has the further advantage of increasing the light; and (3) the light may be increased without much change being made in the duration by making a second gap in the discharge circuit, the spark in which however must be hidden from the plate. Pl. II, fig. 4, shows the trail of the best spark for the purpose of bullet photography that I have obtained up to the present. In this case the surface of the condenser is 1 square foot, and the discharge is taken through bands of copper about 2 inches broad, and not more than about 4 inches long apiece. Extra good contact is made between these copper bands and the tin-foil surface by long radiating tongues of copper-foil soldered to the end of the copper bands. The knobs are platinum, but this seems no better than copper. The whole of the light is extinct in less than one-millionth of a second, while the first blaze, which is practically the whole spark (the tail being in comparison of no consequence) does not last so long as a ten-millionth of a second; in other words, it last so short a time that it bears the same relation to one second that one second bears to four months; or again, a magazine-rifle bullet,

travelling at the enormous speed that is now attained by the use of this weapon, can not go more than one four-hundredth of an inch in this time. Other sparks of still less duration were examined, but this was chosen for the purpose of photographing bullets.*

Now, having obtained a suitable flash of light, I must next show how a spark may be used for the purpose of photographing a bullet in its passage. This was first done by Prof. E. Mach,† of Prague, whose method is illustrated by the diagram, Pl. II, fig. 5. The squares on the right-hand side represent certain electrical apparatus by means of which a Leyden jar (J) is charged with electricity to such an extent that, while it is unable to make two sparks at B and A, it is nevertheless able to, and at once will, make a spark at B when the second gap at A is closed by a bullet or other conductor. The dotted lines represent wires through which the discharge then takes place. The spark at B, magnified by the lens l in front of it, then fills the field lens L with light, so that the camera K focused upon the spark gap A will then receive an image of the bullet as it passes, and thus a photograph is secured. I am able to show two of these which Prof. Mach has kindly forwarded to me, and what I wish to point out is that in each of these photographs—and this is perhaps the most interesting feature which any of these exhibit—there are seen, besides the bullet and the wires which the bullet strikes in its journey, certain curious shades, one in advance of the bullet and one from the tail, while a trail is left behind very like that seen in the wake of a screw steamer. In fact, the whole atmospheric phenomenon accompanying the bullet is not unlike that seen on the surface of water surrounding and behind a steamship. These were seen for the first time, and their visibility by this method was (I believe) predicted by Prof. Mach before he made his first experiment.

The part that I have played in this matter is after all very subordinate. I have attempted to simplify the means, and the results which may be obtained by the modified method which I have devised, are, I believe, in some respects—I don't say in all—clearer and more instructive than those obtained by the more elaborate device of Prof. Mach.

Pl. II, fig. 6, is a diagram of the apparatus that I have used. C is

* These sparks were made to go off at the time that the mirror was facing toward the photographic plate by the employment of the same device as that described below in connection with fig. 4. On the axle of the mirror an insulated tail of aluminium was secured, so as nearly to bridge a gap in the discharge circuit of an auxiliary jar of small capacity, there being a gap common to both circuits. A self-induction coil was used instead of the wet string, as being for this purpose preferable. The length of time that the spark lasted was thus measured without taking the electricity round by the mirror, which would have been quite sufficient to modify the duration of the discharge, and it was easier than making and adjusting a second reflecting mirror, which would have answered the same purpose.

† See *Nature*, vol. XLII, p. 250.

a plate of window glass with a square foot of tin foil on either side. This condenser is charged until its potential is not sufficient to make a spark at each of the gaps E, and E′, though it would, if either of these were made to conduct, immediately cause a spark to form at the other. *c* is a Leyden jar of very small capacity connected with C by wire, as shown by the continuous lines, and by string wetted with a solution of chloride of calcium, as shown by the dotted line. So long as the gap at B is open this little condenser, which is kept at the same potential as the large condenser by means of the wire and wet string, is similarly unable to make sparks both at B and E′, but it could, if B were closed, at once discharge at E′. Now, suppose the bullet to join the wires at B, a minute spark is made at B and at E′ by the discharge of *c*, immediately C, finding one of its gaps E′ in a conducting state, discharges at E, making a brilliant spark, which casts a shadow of the bullet, etc., upon the photographic plate P. Though this is simple enough, the ends that are gained by this contrivance are not so obvious. In the first place the discharge circuit of C, via E and E′ is made of very short broad bands of copper, a form which favors both the brilliancy and the shortness of duration of the sparks; further, the double gap, of which E′ may be the longer, causes the intensity of the light of either spark to be greater than it would be if the other one did not exist—in a particular case the light of the shorter was increased six or eightfold—at the same time the duration is not greatly affected. For this reason the spark at E may be made very short, so that the shadow is almost as sharp as if the light came from a point. The spark formed at B, which is due to the discharge of *c* only, is very feeble, so that it is unable to act on the plate, whereas, had the discharge of C been carried round by B, the light at this point would hopelessly have spoilt the plate, and at the same time the light at E would have been feebler and would have lasted longer.

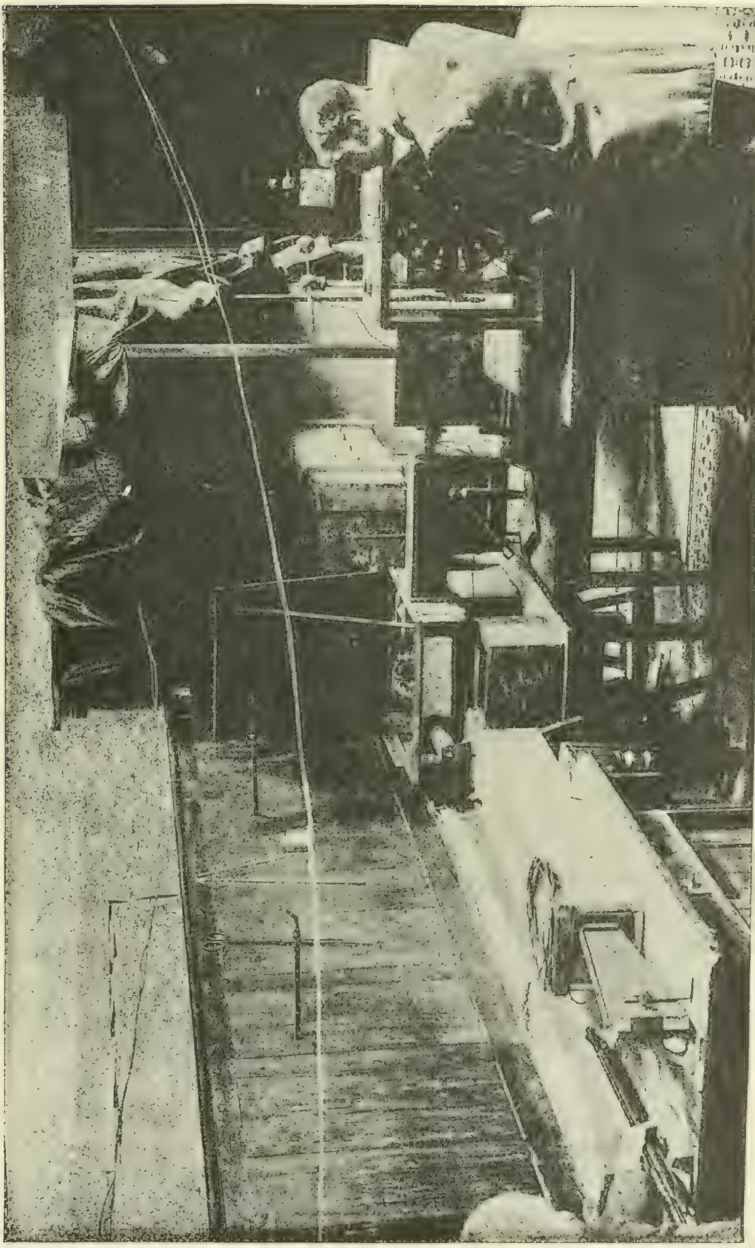
The wet string, while it is for the purpose of keeping the condenser *c* charged a perfect conductor, is nevertheless, when this discharges at E′ and B, practically a perfect insulator; if it were replaced by wire, then C would also wholly or partially discharge itself by B and E′. Finally, in avoiding all lenses one is free from the considerable absorption of the more refrangible rays which sparks provide in great abundance, and which are largely absorbed by glass. On the other hand, the photograph is a mere shadow; but this is no drawback, for the bullet itself is on either system a mere silhouette, whereas the atmospheric phenomena are more sharply defined and their character is more clearly indicated without lenses than is possible when they are employed.

Plate III is a photograph of the apparatus set up in one of the passages in the Royal College of Science, in which the experiments were made. It is apparently of the rudest possible construction. The rifle seen on the left of the figure is of course made to rest freely on six

points,* in order that its position every time it is fired may be the same. The bullet then traverses precisely the same course, so that wires placed in the line between holes in two cards made by one shot will be hit by the next. The two wires which the bullet joins as it passes by are set up in the box seen in the middle of the figure with the lid propped up so as to show the interior. The photographic plate is on the left-hand side, and the spark when made is just within the rectangular prolongation on the right-hand side. Paper tubes with paper ends are placed on each side of the box to allow the bullet to enter and leave, and yet not permit any daylight to fall directly on the plate. All is black inside, and so the small amount of light which does enter the box through these holes is not diffused in any harmful manner. The large box at the back is a case 5 feet long, filled with bran, which stops the bullets gently without marking them.

The little condenser is just below the rectangular prolongation of the photographic box, the large condenser is the vertical square sheet seen just to the right. The electrical machine used to charge the condensers is seen on the table. It is a very beautiful 12-plate Wimshurst machine, made by Mr. Wimshurst and presented to the Physical Laboratory. This machine not only works with certainty but is so regular in its working that no electrometric apparatus is necessary. All that has to be done is to count the number of turns of the handle which are required to produce the sparks at E and E′ when the gap at B is not joined, and to count the number which are sufficient to produce a spark at E when the gap at B is suddenly closed. Then if the rifle is fired after any number of turns between these, but by preference nearer the larger than the smaller number, the potential will be right, the spark E, inside the box, and the spark E′ which is in sight outside the box, will be let off, and if a plate is exposed a photograph will be taken. If by chance the E′ spark is not seen then there is no occasion to waste the plate; another bullet may be fired after resetting the wires and the result will be as good as if one shot had not failed. When all is in order a failure of this kind is very rare. I also arranged a tube in the side of the box with a pocket telescope fixed in it and focused on the wires. If a piece of white card or paper is placed in the line of vision and so as to be illuminated by a spark let off as above described, but preferably much nearer the card, the bullet will be seen by anyone looking through the telescope. I took this down however at once, as the photograph showed more than could ever be

* Six independent points of support are required for a geometrical clamp. In this case a V support near the muzzle supplied two, a V support near the breech two more points. The rifle was pressed forward until a projection under the muzzle rested against the front V, thus allowing freedom of recoil, but otherwise preventing all uncertainty of position except that due to rotation in the ’s, which is made impossible by the sixth point—that is, the lower end of the stock resting sideways against a leather-covered wooden bracket fastened to the same table to which the V's were attached.



APPARATUS FOR PHOTOGRAPHY OF FLYING BULLETS.
(Reprinted from "Nature," by permission of Prof. C. V. Boys.)

seen by the eye. The box seen just to the right of the rifle with a coil of wire upon it is the one in which the revolving mirror was fixed, and in which the trails of sparks made near the door at the end of the passage were photographed. The apparatus for photographing the bullets was put together and set up by Mr. Barton, a student, whose very skillful help in the matter and afterwards during the experiments I found of very great value.

The first photograph which I am able to show was taken at Christmas, before the apparatus just described was put together. It was taken to see if the idea would practically succeed, merely using for the purpose bits of wire and other things to be found in any laboratory, which were set up in a dark room in less than an hour. The first shot was successful, but the sharpness of the photograph is not what it might be, owing to the fact that I used, for the sake of the brilliant light, a spark taken between magnesium terminals. However, the bullet is clearly enough defined, as are the wires which it has just struck. This is a photograph of a pistol bullet traveling only 750 feet a second. You will notice that unlike that taken by Prof. Mach, which represented a shot going at a much higher speed, this photograph shows no atmospheric phenomena surrounding the bullet. I would only add, in connection with this photograph, that by some accident the wad remained attached to the bullet in this case forming the enlarged tail. I do not know if this often happens; it must, if it does, seriously disturb the flight of the projectile, and introduce an anomaly that might not easily be accounted for.

The next photograph, Pl. IV, fig. 1, shows a bullet which has just left a Martini-Henry rifle. This is taken with the apparatus in its latest form, and the bullet appears perfectly sharp. There is no sign of any movement whatever in so far as the bullet itself is concerned. But now that we are dealing with a higher speed, namely, 1,295 feet a second, there is evidence of the movement of the bullet in the form of a wave of compressed air in front and of other waves at the side of and behind the bullet. I shall explain this in a moment, but I would rather first show another photograph, Pl. IV, fig. 2, of a bullet travelling at a still higher speed, a magazine-rifle bullet travelling about 2,000 feet a second, in which these air waves are still more conspicuous, and in which a glance is sufficient to make it evident that the waves are much more inclined to the vertical than in the previous case.

Now, as it may not be evident why these waves of air are formed, why their inclination varies with the speed, or why existing they are visible at all, a short explanation may not be out of place, more especially as they form a most interesting feature in the remaining photographs that I have to exhibit, which can not, as a matter of fact, be properly interpreted without frequent reference to them.

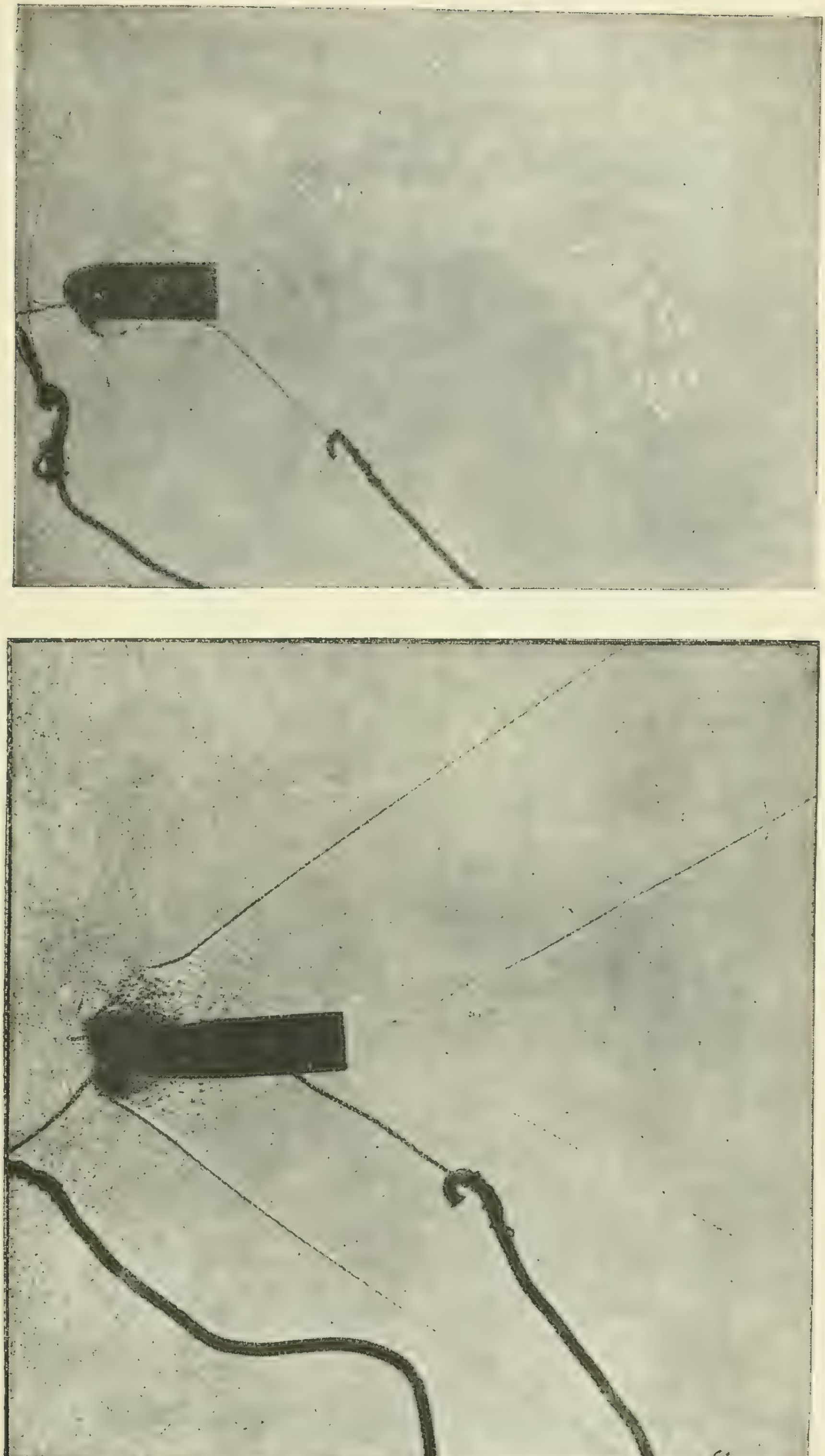
I would first ask you to examine some still water into which a needle held vertically is allowed to dip. If you move the needle very slowly

not a ripple is formed on the surface of the water; but as the needle is moved more quickly at first a speed is reached at which feeble waves appear, and then as the speed increases a swallow-tail pattern appears; the angle between the two tails become less as the velocity gets higher. Now, in the case of water waves the velocity with which they travel depends on the distance between one and the next, and, for a reason into which I must not now enter, either very long or very short waves travel more quickly than waves of moderate dimensions. If they are about two-thirds of an inch long they travel most slowly—about 9 inches a second. Now, so long as the needle is travelling less quickly than this, no disturbance is made; but when this speed is exceeded the swallow-tail appears. Suppose, for example, the velocity of the needle to be double the minimum wave velocity for water, *i. e.*, let the needle move at 18 inches a second, and let it at any moment have arrived at the point *p*, Pl. V, fig. 1,- then any disturbance, started when it was at the point A, must have travelled as far as the circle *aaa* in which A*a* is half A*p*, similarly for any number of points BC, etc., between A and *p* any disturbance must have travelled as far as the corresponding circles *bb*, *cc*, etc., the result is that along a pair of lines, *p*L, *p*M, touching all the circles that could be drawn in this way, a wave will be found, and it is clear that as the velocity of the point is made greater the successive radii A*a* B*b*, etc., will become in proportion to A*p* less, the circles will be smaller, and the angle between L*p* and M*p* will become less, while when the velocity is made less the reverse happens, until at last A*a* B*b*, etc.,   A*p* B*p*, etc., and then when they exceed these quantities no lines L*p* M*p* can be drawn touching all these circles, there is no wave surface which the disturbances from all the successive points can conspire to produce, and the consequence is there is still water.

Now consider the case of a bullet moving through the air. Here again we are dealing with a case in which a wave can not travel at less than a certain speed which is obviously the velocity of sound (1,100 feet a second, under ordinary circumstances), but as in the case of surface waves on water, higher speeds are possible when the wave is one of very great intensity. The conditions in the two cases are therefore very nearly parallel; if the bullet is travelling at less than the minimum speed no waves should be formed; the pistol bullet at 750 feet a second did not show any; if the bullet is travelling at higher speeds than 1,100 feet a second waves should be formed which should include a sharper angle as the speed is made to increase. This was found to be so in the case of the Martini-Henry and the magazine-rifle bullet.

The curved form of the wave near the apex is due to the fact that when it is very intense, when the compression is very great, the velocity of travel is greater and, immediately in front of the bullet, the air is compressed to so great an extent that the wave at this part can travel at the speed of the bullet itself.

The reason why the waves should be visible at all is not difficult to



1

PHOTOGRAPHY OF FLYING BULLETS.

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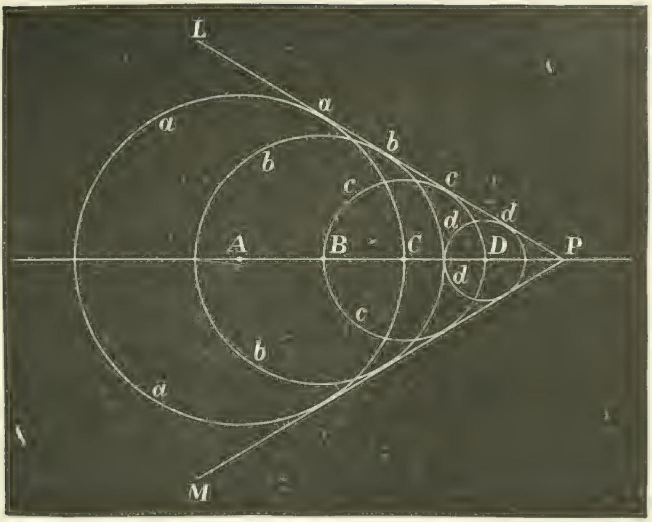

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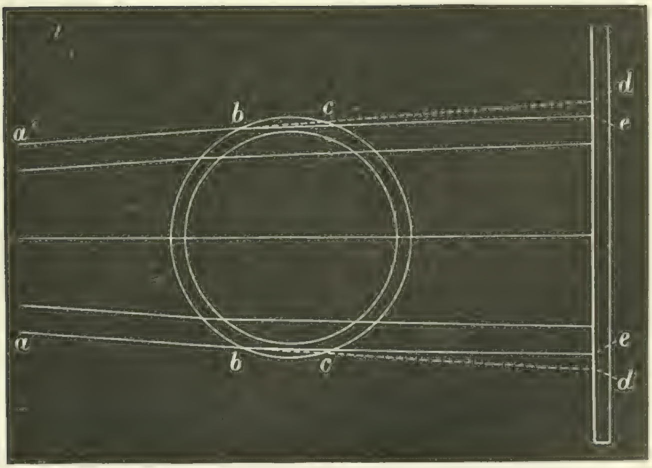

2

PHOTOGRAPHY OF FLYING BULLETS.
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follow. Consider a shell of compressed air through which rays of light from a point are made to traverse. These rays travel in straight lines, except where they meet a medium of different density, and the denser this is and the more nearly they meet this at a grazing incidence the more they will be bent toward the perpendicular. In comparison with water or glass a layer of compressed air has very little refractive power, and so rays which strike the shell anywhere except at the extreme edge are practically uninfluenced in their course and strike the plate practically in the same place that they would do if the shell of compressed air had not been traversed. But those rays *ab*, *ab*, Pl. V, fig. 2, which strike the shell of air almost tangentially, are bent inwards slightly at *b* and again at *c*, having traversed what is equivalent to a wide angle prism, and strike the plate at *e*, leaving the place *d*, where they would have gone had they not been refracted, dark; moreover, at *e* they meet other rays which have been hardly at all refracted since they have passed actually into the shell and out again, and therefore *e* is doubly illuminated. The consequence is that a wave or shell of compressed air gives rise to an image on the plate, in which there is a dark line and a light line within it. Similarly a wave of rarefaction must produce a light line with a dark one within it.*

An examination of the photograph (Pl. IV, fig. 2) will make it evident that not only is the head wave a wave of compression, but the wave which starts from the end of a kind of vena contracta behind the bullet is also a wave of compression. It is a curious fact which requires explanation that the head and tail waves are not parallel to one another, and they do not show any sign that they would become parallel if they were continued indefinitely. This can only be due to either the tail of the bullet travelling considerably faster than the head, or to the actual velocity of propagation of the tail wave being less than that of the head wave The effect observed is true and is not optical, being neither due to the refractive effect of the outer shell disturbing rays which are tangential to the inner shell, nor to an effect of perspective, for though the projection of a cone from a point upon a plane is only seen of the proper angle when the perpendicular, dropped from the point upon the plane, passes through the vertex of the cone, yet when, as in the case of Pl. VII, where it passes within both cones, and more within the outer one than the inner one, the effect is to make the projections of both of a greater obtuseness, and of the outer one to a greater extent than the inner one; nevertheless an examination of the amount of this effect of perspective made by Mr. Barton showed that the distortion

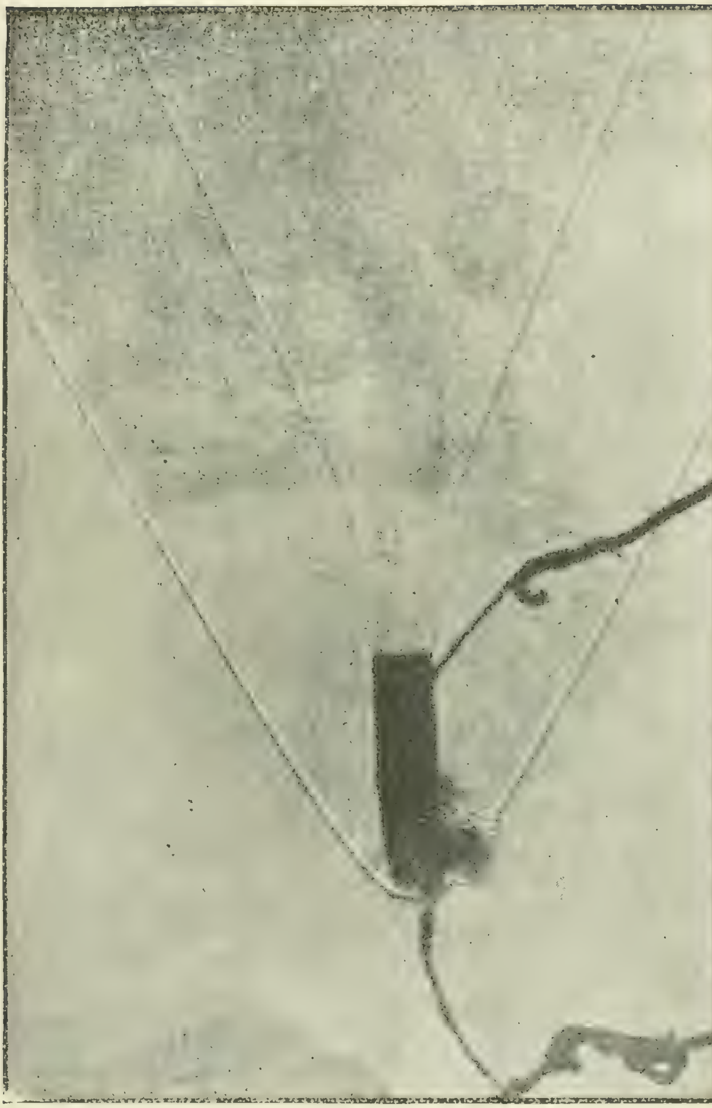
* It may be worth while to point out that the dark and light lines are—and ought to be—parallel to one another as soon as they are so far away from the shadow of the bullet as to be practically straight lines. For if the thickness of the shell is divided up into a series of elements, the ray passing through any one of these will meet with a refractive medium which is less effective, as the diameter of the part of the shell considered is greater, while the refractive angles of the elementary prisms become inclined more, so as to compensate for the diminished density

was not sufficient to be noticeable, as the difference in the acuteness of the cones certainly is.

Going back now to the photographs, the next one was taken with the view of illustrating the effect on the inclination of the waves of the velocity of the bullet. In this case the bullet was aluminum; it was only one-seventh the weight of the regulation bullet. In consequence of its lightness it travelled about half as fast again as the ordinary bullet (not $\sqrt{7}$ times as fast as it would have done if the pressure of the powder gases had been the same in the two cases), and in consequence of the higher speed the inclination of the waves is still greater than in the previous case. Further, in this case the bullet was made to pierce a piece of card shortly before it was photographed. The little pieces that were cut out were driven forward at a high speed, but, being lighter than the bullet, they soon lost a large part of their velocity; they had in consequence lagged behind when they were photographed, but though travelling more slowly (they were still going at more than 1,100 feet a second) they yet made each its own air wave, which became less and less inclined as the bits lagged more and more behind; each, moreover, produced its own trail of vortices like that following the bullet. The well-known fact that moving things tend to take the position of greatest resistance, to avoid the effect of which the bullet has to be made to spin, is also illustrated in the photograph. The little pieces that are large enough to be clearly seen are moving broadside on, and not edgeways, as might be expected.

In order to illustrate the other fact that the angle of the waves also depends on the velocity of sound in the gas, I filled the box with a mixture of carbonic-acid gas, and the vapor of ether, a mixture which is very dense, and through which sound in consequence travels only about half as fast as it does in air, and which will not explode or even catch fire when an electric spark is made within it, or directly act injuriously upon the photographic plate. The increased inclination of the waves is very evident in Plate VI.

These waves, revealed by photography, have a very important effect on the flight of projectiles. Just as in the case of waves produced by the motion of a ship, which, as is well known, become enormously more energetic as the velocity increases, and which at high velocities produce as a matter of fact an effect of resistance to the motion of the ship of far greater importance than the skin friction, so in the case of the air waves produced by bullets; in its flight the resistance which the bullet meets with increases very rapidly when the velocity is raised beyond the point at which these waves begin to be formed. This being the case, I have thought it might be interesting to see whether the analogy between the behavior of the two classes of waves might be even nearer than has already appeared, and on turning to the beautiful researches of Mr. Scott Russell, published in the report of the British Association for the year 1844, in which he gives a very full



PHOTOGRAPHY OF FLYING BULLETS.
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report on the water waves and their properties, I found that he had made experiments and had given a diagram showing what happens when a solitary wave meets a vertical wall. The wave, as would be expected, is, under ordinary conditions, reflected perfectly, making an angle of reflection equal to the angle of incidence, and the reflected and incident waves are alike in all respects. This continues to be the case as the angle gets more and more nearly equal to the right angle, *i. e.*, until the wave front, nearly perpendicular to the wall, runs along nearly parallel to it. It then at last ceases to be reflected at all. The part of the wave near the wall instead gathers strength, it gets higher, it therefore travels faster, and so causes the wave near the wall to run ahead of its proper position, producing a bend in the wave front, and this goes on until at last the wave near the wall becomes a breaker.

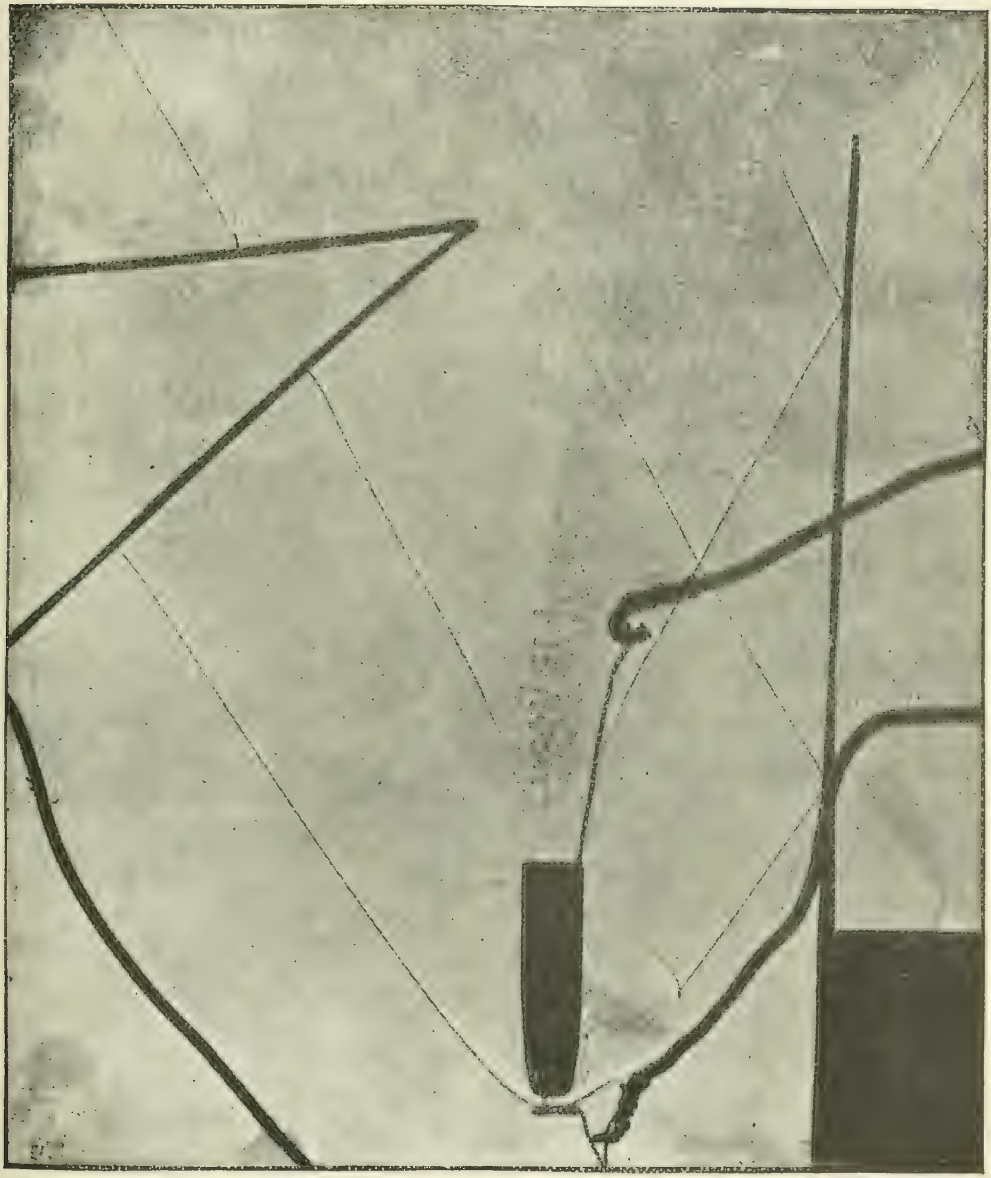
In order to see if anything similar happens in the case of air waves, I arranged the three reflecting surfaces of sheet copper seen in Plate VII, and photographed a magazine-rifle bullet when it had got to the position seen. Below the bullet two waves strike the reflector at a low angle, and they are perfectly reflected, the dark and the light lines changing places as they obviously ought to do. The left side of the V-shaped reflector was met at a nearly grazing incidence; there there is no reflection, but, as is clear on the photograph, the wave near the reflector is of greater intensity, it has bent itself ahead of its proper position as the water wave was found to do, but it can not form a breaker, as there is no such thing in an air wave. The same photograph shows two other phenomena which are of interest. The stern wave has a piece cut out of it by the lower reflector, and bent up at the same angle. Now if a wave was a mere advancing thing the end of the bent-up piece would leave off suddenly, and the break in the direct wave would do the same. But according to the view of wave propagation put forward by Huygens, the wave at any epoch is the resultant of all the disturbances which may be considered to have started from all points of the wave front at any preceding epoch. The reflector, where it has cut this wave, may be considered as a series of points of disturbance arranged continuously in a line, each however coming into operation just after the neighbor on one side and just before the neighbor on the other. The reflected wave is the envelope of a series of spheres beginning with a point at the place where the wave and the reflector cut, growing up to a finite sphere about the end of the reflector as a center; beyond this there are no more centers of disturbance, the envelope of all the spheres projected upon the plate, that is, the photograph of the reflected wave, is not therefore a straight line leaving off abruptly, but it curls round, as is very clearly shown, dying gradually away to nothing. The same is the case, but it is less marked, at the end of the direct wave near the part that has been cut out.

The other point to which I would refer is the dark line between the nose of the bullet and the wire placed to receive it. This is the feeble spark due to the discharge of the small condenser which clearly must have been on the point of going off of its own accord. The feeble spark precedes—or is to all intents and purposes simultaneous with, it cannot follow—the main spark which makes the photograph. The feeble spark heated the air, and the light from the main spark coming through this line of heated air was dispersed, leaving a clear black shadow on the plate. One spark casts a shadow of the other. Now it is evident that if the spark at the nose of the bullet had followed instead of having preceded the main spark by even so much as a three-hundred-millionth of a second, the time that light took to travel from one to the other, it would not have been able to cast a shadow. We have the means of telling, therefore, which of two sparks actually took place first, or perhaps the order of several, even though the difference of time is so minute. Perhaps this method might be of some use in researches now attracting so much interest in connection with the propagation of electrical waves.

On returning to the non-reflection of the air wave in the upper part of the figure, we have here, I imagine, optical evidence of what goes on in a whispering gallery. The sound is probably not reflected at all, but runs round almost on the surface of the wall from one part to another.

We are now in a position to see how the reflection or non-reflection of air waves produced by a passing bullet, when they meet with some solid body, may produce a practical result which might be of importance in some cases. Suppose a bullet to be passing near and parallel to a wall. Then if the velocity of the bullet and its distance from the wall are such that the head wave meets the wall at an angle at which it can be reflected, especially, as in the case of Plate VII, if the reflected ray can only return into the path of the bullet after it has gone, then no influence whatever can be exerted upon the bullet by its proximity to the wall. If however the head wave would if undisturbed meet the wall at such an angle that it could not be reflected, as for instance in Plate VIII, when the head wave can be reflected by neither of the walls between which the bullet is passing, obviously the wave will become stronger and the resistance which it offers will, I imagine, become greater, and if in this case the upper plate be removed this extra resistance will be one-sided and must tend to deflect the bullet. This is quite distinct from the well-known effect of a bayonet upon the path of a bullet; when a bayonet is fixed the rush of powder gases between the bullet and the bayonet is quite sufficient to account for the deflection which every practiced marksman allows for.

I have devised a method by which a problem of some difficulty, about which authorities are, I believe, by no means in accord, may be solved with a fair degree of certainty. The problem is this, to find what pro-



PHOTOGRAPHY OF FLYING BULLETS.

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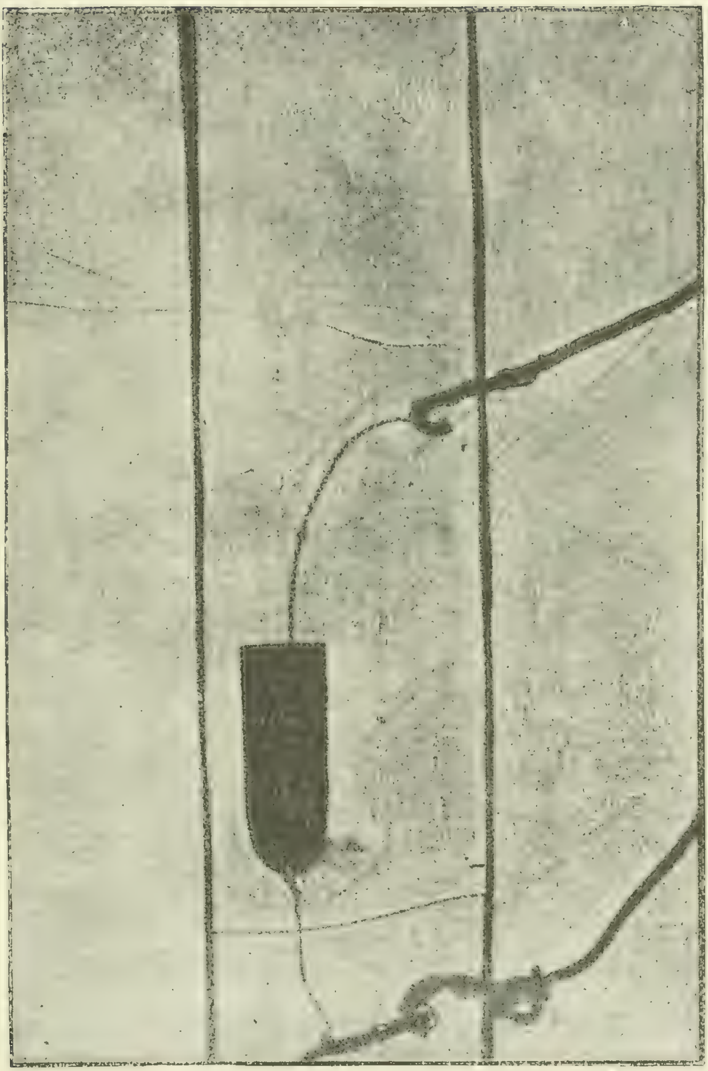

PHOTOGRAPHY OF FLYING BULLETS.

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portion of the velocity of a bullet is given to it after it has left the barrel, or, what comes to the same thing, to find the position in front of the barrel at which the speed is a maximum. The cause of this is evident. When the bullet has left the muzzle the imprisoned powder gases, under enormous pressure, rush out, making a draft past the bullet of the most tremendous intensity tending obviously to drive it forward. While this draught does most assuredly hurry the bullet on its forward course, it does not tend to make it spin round any faster. Now if the bullet were not hurried on at all after it left the muzzle it would, travelling as in a screw of the same pitch all the way from the breech of the rifle up to the point at which it is photographed, have turned round a certain number of times, which depend upon the distance traveled and the pitch of the screw. If however the longitudinal motion is hurried and the rotational is left unaltered the pitch will be lengthened outside the barrel and the rotation will have been less for any position than it would have been if the bullet had not been accelerated in this way. If therefore we can find to what extent the bullet has turned actually at the place at which it has been photographed, we can find the apparent rotational lag, and so working backwards get a measure of the velocity acquired after leaving the muzzle. In order to accomplish this I drilled a series of holes transversely through the bullet, each one at an angle to the previous one, the whole series being such that to whatever extent the bullet had twisted, one at least, and perhaps two, would allow the light of the spark to shine through it upon the photographic plate. Then from the photograph it is easy to see through which hole the light shone, and knowing in what position this was in the breech, it is easy to find what fraction of half a turn over or above any whole number of half turns the bullet has twisted. Strictly the measure should be made at different distances to eliminate all uncertainty, but the only shot I have taken was sufficient to show that there was a rotational lag equivalent, according to the measure made by Mr. Barton, to something under a two per cent acceleration outside the barrel. I do not attach any importance to this figure; the experiment was made with a view to see if the method was practicable and this it certainly is. I would recommend, where accuracy is required, that having found as above about how much the bullet has turned, that a second bullet should be drilled with a series of holes at about the corresponding position differing very slightly from one another in angular position, so that several would let the light through and thus give a more accurate measure of the rotation.

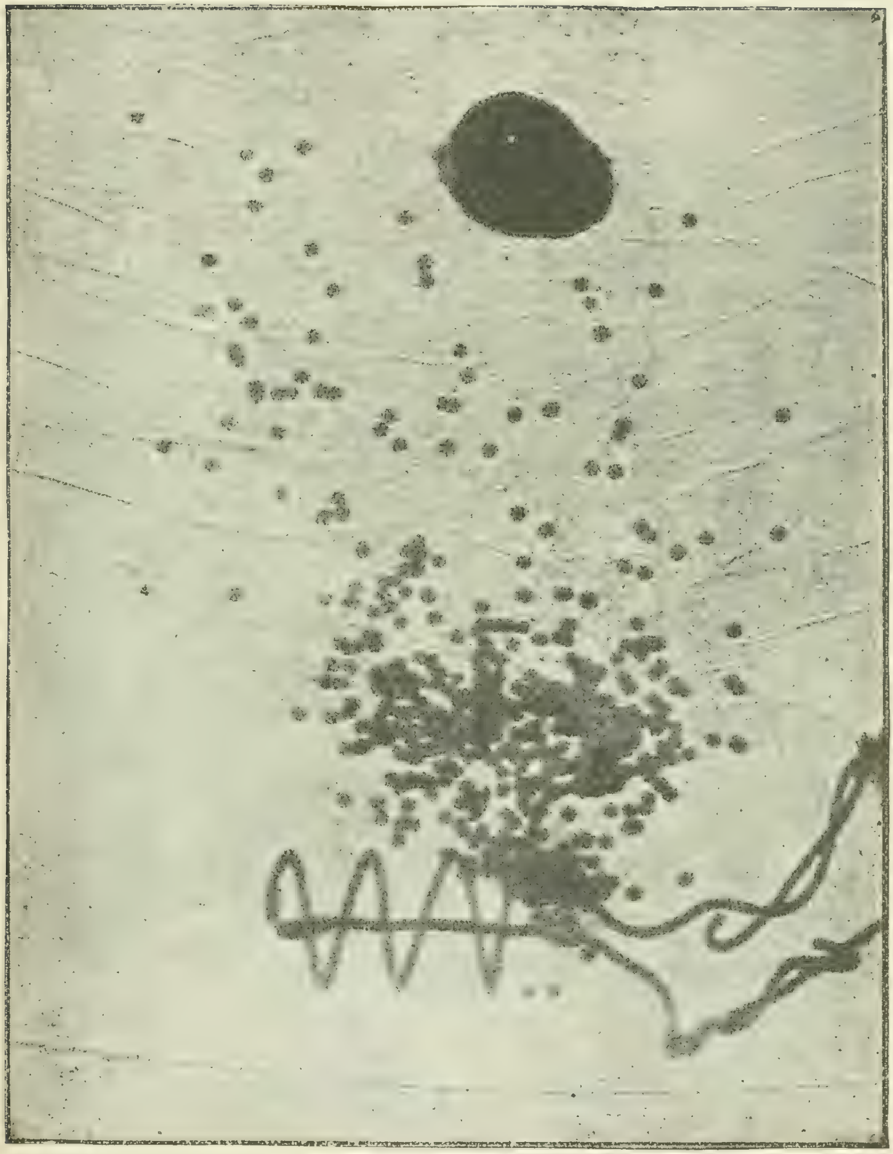
There is a point of interest to sportsmen which has given rise to a controversy which the spark photographs supply the means of settling. The action of the choke bore has been disputed, some having held that the shot are made to travel more compactly altogether, while others, while they admit that the shot are less scattered laterally, as may be proved by firing at a target, assert that they are spread out longitudinally, so that if this is the case the improved target pattern is no cri-

terion of harder hitting, especially in the case of a bird flying rapidly across the direction of aim.

I was unfortunately not able, in the limited space and time that I have been able to employ, to take photographs of the shot at a reasonable distance from the gun, but I have taken comparative photographs at three or four yards only in which every shot is clearly defined, and in which it is even easy to see on the negative where the shot have been jammed into one another and dented. The difference in the scattering at this short distance is not sufficient for the results to give any information beyond this, that shot are as easily photographed as bullets, and that no difficulty need be apprehended in attempting to solve any question of the kind by this method. The photograph, Plate IX, represents the shot from the cylindrical or right-hand barrel. The velocity now is so low that individual waves are no longer formed by each shot. The whole space however occupied by the shot is filled with air waves of the greatest complexity. They are not due to the cause already explained, but are, I believe, formed by the imperfect mixture of air with powder gases still accompanying the shot. The imperfect mixture of the two gases causes light to be deflected in its passage, thus producing striæ, just as at the first mixing of whisky and water striæ are seen (sometimes attributed to oil!), which disappear when the mixture is complete. I would mention, for the benefit of any one who may be tempted to continue these experiments, that a pair of wires (such as are found to do so well when bullets have to be caught) are not suitable, as one is sure to be shot away before such a bridge of shot is made between them as will allow a spark to pass. However, by using thick copper wires, one bent in the form of a screw, with the other along the axis, no such failure can occur, and every shot that I have taken in this way has been successful. One can of course test the action of any material mixed with the shot. For instance, in one case I mixed a few drops of liquid oil with the shot and found them more widely scattered in consequence, not, as has been stated, held together by the oil as if they were in a wire cartridge. Of course, solid grease or fat may, and no doubt does, produce such a result, but liquid oil certainly does not.

And now I wish to conclude with a series of photographs which show how completely the method is under control, how information of a kind that might seem to be outside the reach of experiment may be obtained from the electric-spark photograph, and how phenomena of an unexpected nature are liable to appear when making any new experiment. The result however is otherwise of but little interest or importance.

I thought I should like to watch the process of the piercing of a glass plate by a bullet from the first shock step by step, until the bullet had at last emerged from the confusion it had created. In Plate X, the glass plate is seen edgeways just after the bullet has struck it. It is clear at once that the splash of glass dust backwards is already



PHOTOGRAPHY OF FLYING BULLETS; SHOWING AIR WAVES.
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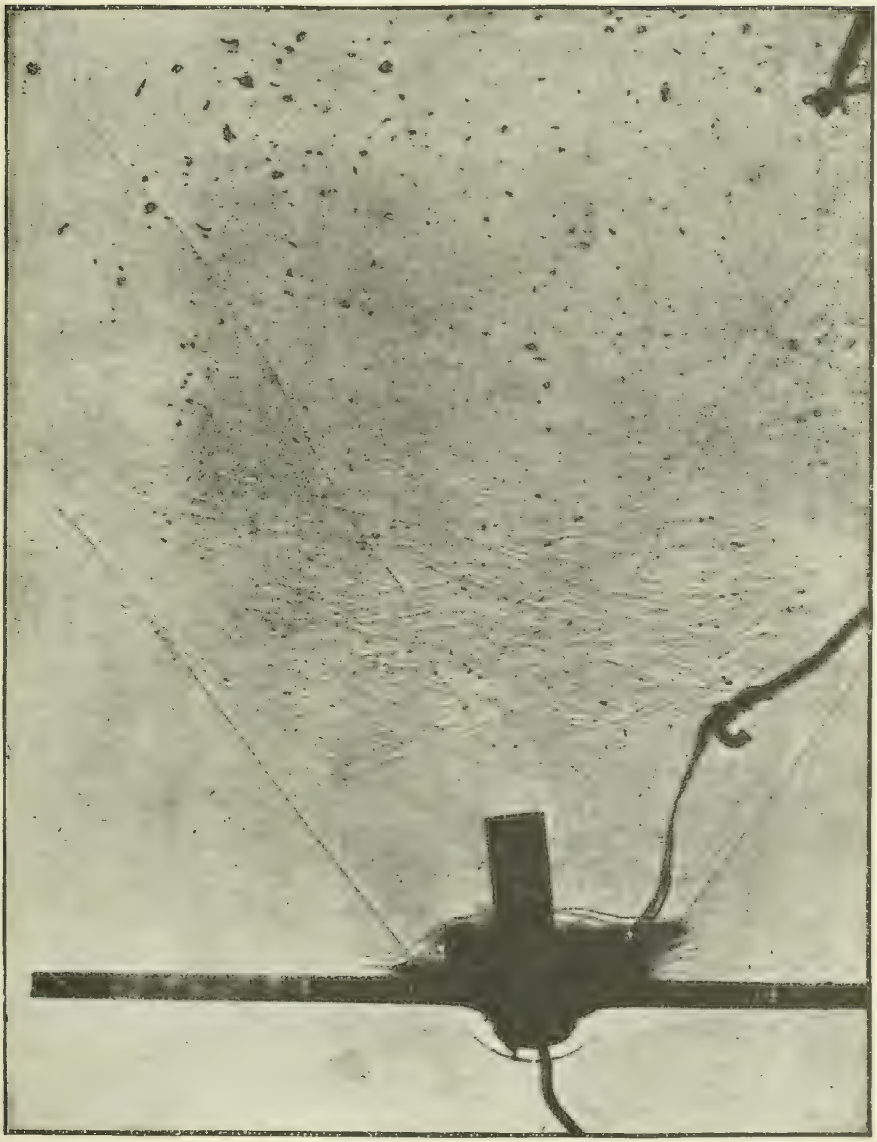


PHOTOGRAPHY OF FLYING BULLETS; SHOT THROUGH GLASS.

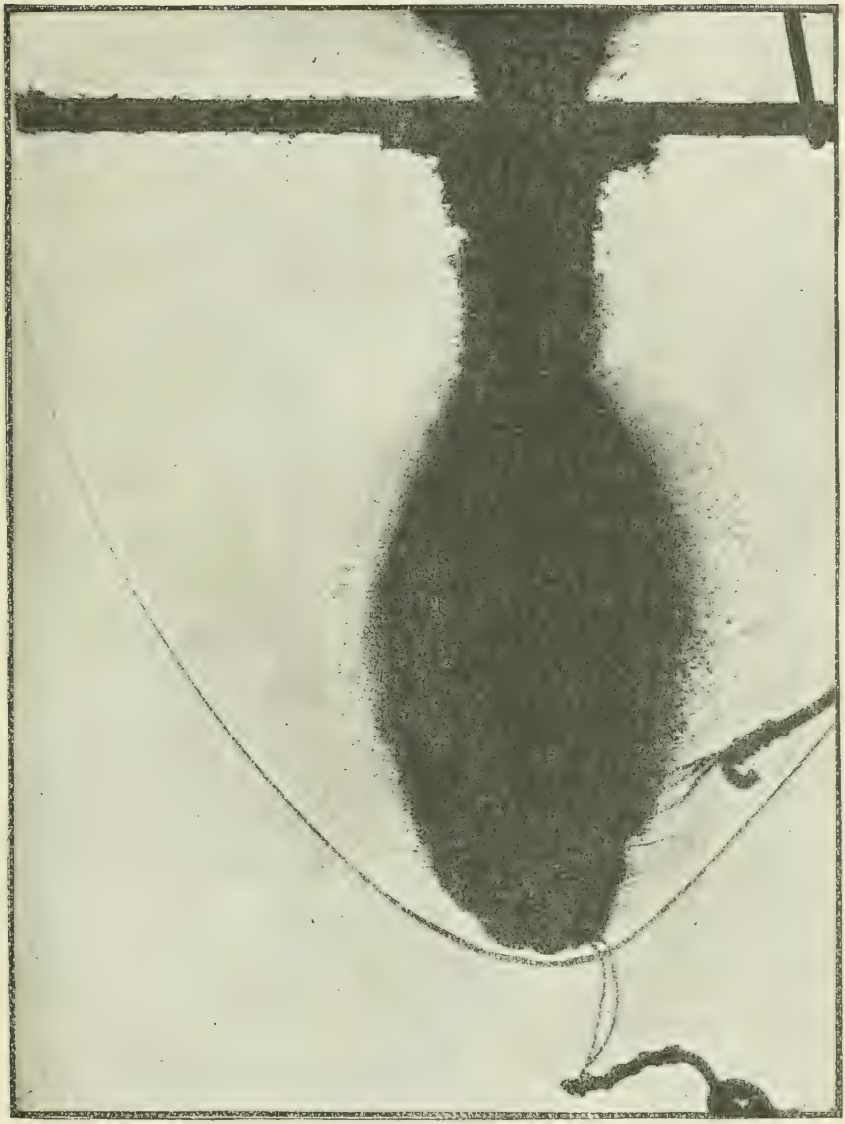
(Reprinted from "Nature," by permission of Prof. C. V. Boys.)

four or five times as rapid as the motion of the bullet forwards. A new air wave is just beginning to be created in front of the glass-coated head of the bullet and two highly inclined waves, one on either side of the glass, reaching about three-quarters of the way to the edge, have sprung into existence. These are more clearly seen in the next figure; meanwhile it may be well to point out that the fragments of paper which are following the bullets have in this case—as the card was much nearer to the glass plate than in those previously taken—some of them lost so much of their velocity and have in consequence lagged behind in a still higher proportion than the others, that they are travelling at less than 1,100 feet a second; the more backward ones carry in consequence no air waves and there is no means of telling from the photograph that they are moving at all. In Pl. XII, fig. 1, the bullet has struggled about half way through the plate. The waves on either side of the plate have now reached the edge and are on their way back towards the center again. They are caused in this way: When the bullet strikes the plate the violent shock produces a ripple or tremor in the glass which travels away radially in all directions, leaving the glass quiet behind. The rate at which this ripple travels may be found from the angle which these new air waves make with the plate, for taking any point on the plate and measuring up to the point where the air wave meets the plate and also the distance in air to the nearest point of the inclined air wave, we get two distances, the ratio of which is the ratio of the velocity of the disturbance in the glass to the velocity of sound in air. But much more than this is shown. An examination of the negatives or of a photographic print and even, but less clearly, of the print in the text shows that these inclined air waves are made up of a series of dark and light lines at a very slight inclination to the air wave itself, so that as we travel along the air wave it is alternately dark outside, and light outside.

These indicate the successive positions in which the glass first moved outwards to compress the air or first moved inwards to rarefy it so that the wave length of the ripple may thus be found, and finally it is seen that where the waves are waves of compression on one side of the plate they are waves to rarefaction on the other, indicating that it was a transverse and not a mere longitudinal disturbance that ran along the plate from the center outwards and back again after reflection from the edge. In addition to this fact that the reflected wave is still on its inward course proves that up to this time the plate is whole, as a wave can not be propagated in a broken plate. Plate XI, illustrates the state of affairs when the bullet has traveled about 5 inches beyond the plate. It has not yet emerged from the cloud of glass dust. The new head wave is very conspicuous. In the original negative, about halfway between the bullet and the plate, the inclined waves due to the tremor in the glass plate may be detected, but they are too delicate to be re-produced by the printing process. They supply the information as

to how long the plate remained whole or rather if the bullet had been caught a little sooner before these faint waves had lost so much of their distinctness they would supply this information with great exactness. Meanwhile the figure shows that the plate is now broken up completely. It is true it is still standing, and the stern air wave is seen reflected from the upper part of it, but this is because the different parts have not yet had time to get away; their grinding edges however have cast out from the surface little particles, and these are seen over the whole extent of the plate. After about 15 inches the bullet is quite clear of the cloud of dust (Pl. XII, fig. 2): one piece only of the glass, no doubt the piece that was immediately struck, has been punched out and is travelling along above the bullet at a speed practically equal to its own. I am also able to show the plate itself in this and a still later stage, when at last the separate pieces have begun to be visibly moved out of their position and in some cases slightly turned round.

I have merely given this evening an account of a few experiments which in themselves perhaps are of little interest, but they at any rate show the capability of this method for the examination of subjects which would in the ordinary way be considered beyond the reach of experiment. It is hardly necessary to say that the examples given by no means reach the limit of what may be done. I have examined the explosions produced by 15-grain fulminate of mercury detonators and of heaps of iodide of nitrogen, a material which is rather unmanageable, as if a fly even walks over it it violently explodes. In these cases the explosive flash was used to make the B gap of Pl. II, fig. 5 conducting, for which it answered perfectly. One might in the same way examine the form of the out-rush of powder gases past the bullet, and so find at once their velocity with respect to the velocity of the bullet, and I see no great difficulty in tracing, if this should be desired, the whole course of a single bullet for perhaps as much as 100 yards by means of photographs taken every few inches on its way. Though it may not be evident that these or similar experiments are of any practical importance, there can be no doubt that information may be readily obtained by the aid of the spark photograph, as in fact has been shown by Prof. Mach, Lord Rayleigh, Mr. F. J. Smith, and others, which without its aid can only be surmised, and that if, as in other subjects, the first wish of the experimentalist is to see what he is doing, then in these cases surely, where in general people would not think of attempting to look with their natural eyes, it may be worth while to take advantage of this electro-photographic eye.



PHOTOGRAPHY OF FLYING BULLETS.

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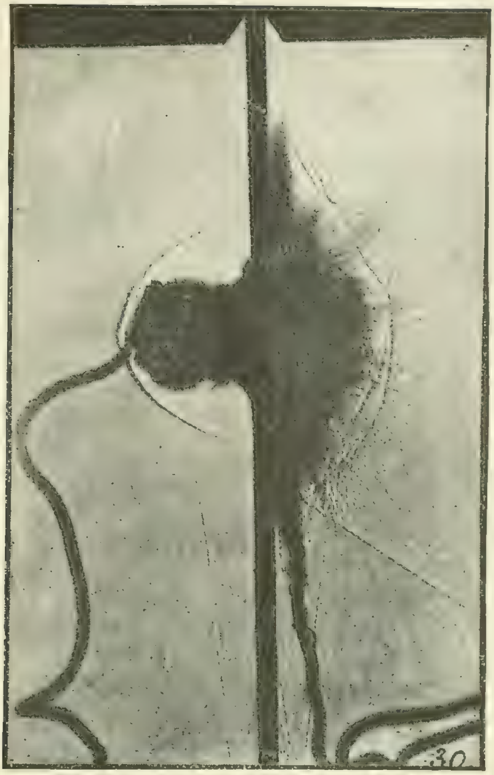

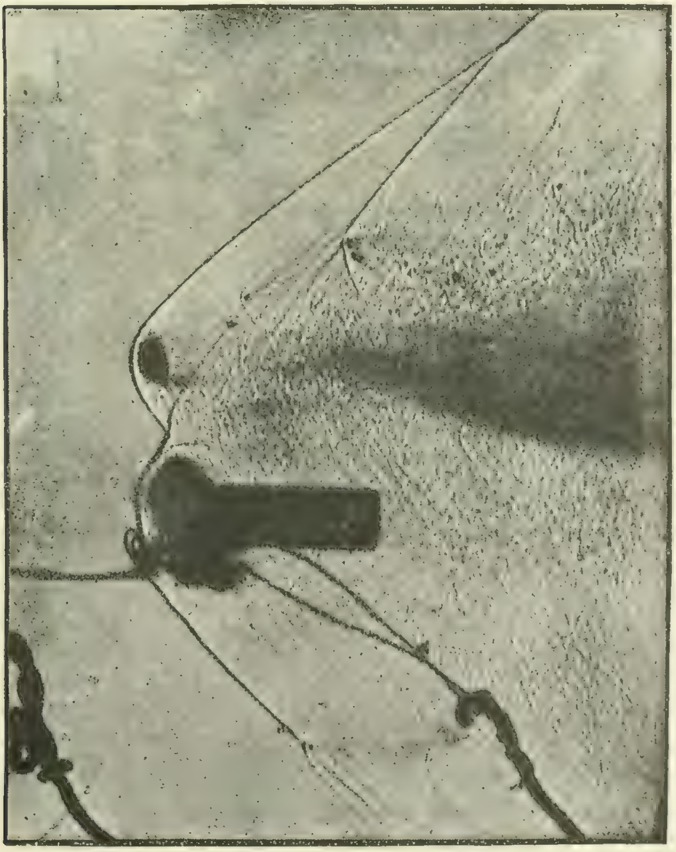

PHOTOGRAPHY OF FLYING BULLETS.

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MAGNETIC PROPERTIES OF LIQUID OXYGEN.*

By Prof. JAMES DEWAR, F. R. S.

After alluding to the generous aid which he had received both from the Royal Institution and from others in connection with his researches on the properties of liquid oxygen, and to the untiring assistance rendered him by his co-workers in the laboratory, Prof. Dewar said that on the occasion of the commemoration of the centenary of the birth of Michael Faraday he had demonstrated some of the properties of liquid oxygen. He hoped that evening to go several steps further, and to show liquid air, and to render visible some of its more extraordinary properties.

The apparatus employed consisted of the gas-engine down stairs, which was driving two compressors. The chamber containing the oxygen to be liquefied was surrounded by two circuits, one traversed by ethylene, the other by nitrous oxide. Some liquid ethylene was admitted to the chamber belonging to its circuit, and there evaporated. It was then returned to the compressor as gas and liquefied, and thence again into the compressor as required. A similar cycle of operations was carried out with the nitrous oxide. There was a hundredweight of liquid ethylene prepared for the experiment. Ethylene was obtained from alcohol by the action of strong sulphuric acid. Its manufacture was exceedingly difficult, because dangerous, and as the efficiency of the process only amounted to 15 or 20 per cent the preparation of a hundredweight of liquid was no light task. The cycle of operations, which, for want of time, was not fully explained, was the same as that commonly employed in refrigerating machinery working with ether or ammonia.

The lecturer then exhibited to the audience a pint of liquid oxygen, which by its cloudy appearance showed that it contained traces of impurity. The oxygen was filtered, and then appeared as a clear transparent liquid with a slightly blue tinge. The density of oxygen gas at −182° C. is normal, and the latent heat of volatilization of the liquid is about 80 units. The capillarity of liquid oxygen at its boiling-point was

* Abstract of discourse delivered at the Royal Institution, Friday evening, June 10, 1892. (From *Proceedings of the Royal Institution of Great Britain*, vol. XIII, pp. 695-699.)

about one-sixth that of water. The temperature of liquid oxygen at atmospheric pressure, determined by the specific heat method, using platinum and silver, was −180° C.

Reference was then made to a remarkable experimental corroboration of the correctness for exceedingly low temperatures of Lord Kelvin and Prof. Tait's thermo-electric diagram. If the lines of copper and platinum were prolonged in the direction of negative temperature, they would intersect at − 95° C. Similarly, the copper and palladium lines would cut one another at −170° C. Now, if this diagrm were correct, the E. M. F. of the thermo-electric junctions of these two pairs of metals should reverse at these points. A Cu−Pt junction connected to a reflecting galvanometer was then placed in oxygen vapor and cooled down. At −100° C. the spot of light stopped and reversed. A Cu−Pd junction was afterwards placed in a tube containing liquid oxygen, and a similar reversal took place at about −170° C.

Liquid oxygen is a non-conductor of electricity: a spark taken from an induction coil, one millimeter long in the liquid, requires a potential equal to a striking distance in air of 25 millimeters. It gave a flash now and then, when a bubble of the oxygen vapor in the boiling liquid came between the terminals. Thus liquid oxygen is a high insulator. When the spark is taken from a Wimshurst machine the oxygen appears to allow the passage of a discharge to take place with much greater ease. The spectrum of the spark taken in the liqud is a continuous one, showing all the absorption bands.

As to its absorption spectrum, the lines A and B of the solar spectrum are due to oxygen, and they came out strongly when the liquid was interposed in the path of the rays from the electric lamp. Both the liquid and the highly compressed gas show a series of five absorption bands, situated respectively in the orange, yellow, green, and blue of the spectrum.

Experiments prove that gaseous and liquid oxygen have substantially the same absorption spectra. This is a very noteworthy conclusion, considering that no compound of oxygen, so far as is known, gives the absorptions of oxygen. The persistency of the absorption through the stages of gaseous condensation towards complete liquidity implies a persistency of molecular constitution which we should hardly have expected. The absorptions of the class to which A and B belong must be those most easily assumed by the diatomic molecules (O_2) of ordinary oxygen: whereas the diffuse bands above referred to, seeing they have intensities proportioned to the square of the density of the gas, must depend on a change produced by compression. This may be brought about in two ways, either by the formation of more complex molecules, or by the constraint to which the molecules are subjected during their encounters with one another.

When the evaporation of liquid oxygen is accelerated by the action of a high expansion pump and an open test-tube is inserted into it, the

tube begins to fill up with liquid atmospheric air, produced at the ordinary barometric pressure.

Dr. Janssen had recently been making prolonged and careful experiments on Mont Blanc, and he found that these oxygen lines disappeared more and more from the solar spectrum as he reached higher altitudes. The lines at all elevations come out more strongly when the sun is low, because the rays then have to traverse greater thicknesses of the earth's atmosphere.

Michael Faraday's experiments made in 1849 on the action of magnetism on gases opened up a new field of investigation. The following table in which + means "magnetic" and — means "negative," summarizes the results of Faraday's experiments.

Magnetic relations of gases (Faraday).

	In air.	In carbonic acid.	In hydrogen.	In coal gas.
Air	○	+	+ weak.	+
Nitrogen	—	—	— strong.	—
Oxygen	+	+	+ strong.	+ strong.
Carbonic acid	....	○	—	— weak.
Carbonic oxide	—	—	—	— weak.
Nitric oxide	— weak.	+	+	....
Ethylene	—	—	—	— weak.
Ammonia	—	—	—	....
Hydrochloric acid	—	—	— weak.	....

Becquerel was before Faraday in experimenting upon this subject. Becquerel allowed charcoal to absorb gases, and then examined the properties of such charcoal in the magnetic field. He thus discovered the magnetic properties of oxygen to be strong, even in relation to a solution of ferrous chloride, as set forth in the following table:

Specific magnetism, equal weights (Becquerel).

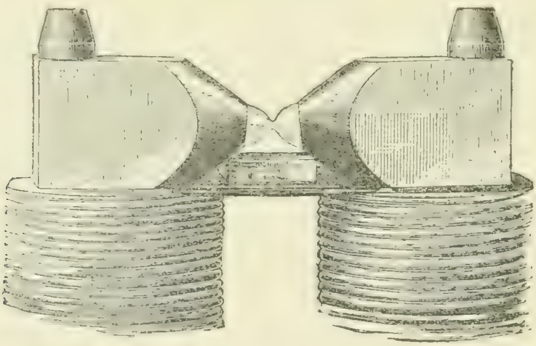
Iron	+	1,000,000
Oxygen	+	377
Ferrous chloride solution, sp. gr. 1·4334	+	140
Air	+	88
Water	—	3

The lecturer took a cup made of rock salt and put in it some liquid oxygen. The liquid did not wet rock salt, but remained in a spheroidal state. The cup and its contents were placed between and a little below the poles of an electro-magnet. Whenever the circuit was completed the liquid oxygen rose from the cup and connected the two poles, as represented in the cut, which is copied from a photograph of the phenomenon. Then it boiled away, sometimes more on one pole than the other, and when the circuit was broken it fell off the pole in drops back into the cup. He also showed that the magnet would draw up liquid oxygen out of a tube. A test-tube containing liquid oxygen,

when placed in the Hughes balance, produced no disturbing effect. The magnetic moment of liquid oxygen is about 1,000 when the magnetic moment of iron is taken as 1,000,000. On cooling, some bodies increased in magnetic power. Cotton wool, moistened with liquid oxygen, was strongly attracted by the magnet, and the liquid oxygen was actually sucked out of it on to the poles. A crystal of ferrous sulphate, similarly cooled, stuck to one of the poles.

The lecturer remarked that fluorine is so much like oxygen in its properties that he ventured to predict that it will turn out to be a magnetic gas.

Nitrogen liquefies at a lower temperature than oxygen, and one would expect the oxygen to come down before the nitrogen when air is liquefied, as stated in some text-books, but unfortunately it is not true. They liquefy together. In evaporating however, the nitrogen boils off before the oxygen. He poured two or three ounces of liquid air into a large test tube, and a smouldering splinter of wood dipped into the mouth of the tube was not re-ignited; the bulk of the nitrogen was nearly five minutes in boiling off, after which a smouldering splinter dipped into the mouth of the test tube burst into flame.



Magnetic properties of liquid oxygen.

Between the poles of the magnet all the liquefied air went to the poles; there was no separation of the oxygen and nitrogen. Liquid air has the same high insulating power as liquid oxygen. The phenomena presented by liquefied gases present an unlimited field for investigation. At — 200° C. the molecules of oxygen had only one-half of their ordinary velocity, and had lost three-fourths of their energy. At such low temperatures they seemed to be drawing near what might be called "the death of matter," so far as chemical action was concerned; liquid oxygen, for instance, had no action upon a piece of phosphorus and potassium or sodium dropped into it; and once he thought, and publicly stated, that at such temperatures all chemical action ceased. That statement required some qualification, because a photographic plate placed in liquid oxygen could be acted upon by

radiant energy, and at a temperature of — 200° C. was still sensitive to light.

Prof. M'Kendrick had tried the effect of these low temperatures upon the spores of microbic organisms, by submitting in sealed glass tubes blood, milk, flesh, and such like substances, for one hour to a temperature of — 182° C., and subsequently keeping them at blood heat for some days. The tubes on being opened were all putrid. Seeds also withstood the action of a similar amount of cold.

[At a meeting of the Royal Society of London, held March 9, 1893, Professor Dewar made an oral statement to the effect that he had succeeded in freezing liquified atmospheric air into a clear transparent solid. Whether this solid is a jelly of solid nitrogen containing liquid oxygen, or a true ice of liquid air, in which both oxygen and nitrogen exist in the solid form, was however stated to be a question for further research.—*Proceedings of the Royal Society*, 1893, vol. LIII, p. 80.]

THE PROBLEM OF FLYING.*

By Otto Lilienthal.

While theoretically no difficulty of any considerable importance precludes flight, the problem can not be considered solved until the act of flying has been accomplished by man. In its application, however, unforeseen difficulties arise of which the theorist can have no conception.

The first obstacle to be overcome by the practical constructor is that of stability. It is an old adage that "*Wasser hat keine Balken.*"† What then, shall be said of air?

Leaving out of the question propelling mechanisms which require more than ordinary refinements of construction, theory teaches that a properly constructed flying apparatus may be brought to sail in a sufficiently strong wind; while in still air, such a machine may be made to glide downward upon a slightly inclined path. In the practical application of these two methods, however, it is found that while the apparatus is supported by moving air, it is also subjected to the whims of the wind, which often places it in uncomfortable positions, overturns it, or carries it into higher regions and then precipitates it, headforemost, to the ground. Lowering of the center of gravity is of little avail, nor does the most ingenious change of the wings or the steering surfaces alter the case. There is still no trace of the majestic soaring of the bird, for the wind is a treacherous fellow, who follows his own inclinations and laughs at our art. Therefore let us try the second method, the oblique descent in still air.

According to computation the apparatus should descend at a small angle, reaching the ground at a considerable distance, but this experiment is a success only in short flights. Beyond these the apparatus becomes unmanageable, darts vertically up, turns about, comes to a full stop, stands on its head, and descends with uncomfortable rapidity to the ground, the contact with which will probably have demolished the machine, if it do not turn a lucky somersault and land upon its

* Translated abstract of a paper from *Prometheus*, No. 205, 1893, vol. IV, pp. 769–771.
† Water has no rafters.

back. Nor do repeated changes of the center of gravity alter the case beyond making it turn over backward instead of forward, leaving the conditions as unstable as before. Fancy the fate of the man who confides in such an apparatus.

Shall we now give up all hopes of success or shall we try new means to deprive the flying machine of its vicious propensities? This question has been answered in various ways. On the one hand it is thought that it should be possible, by mechanical means, to produce stable flight automatically, and an association of engineers of repute at Augsburg—an excellent proof that investigations of the art of flying have begun to be taken up by willing and self-sacrificing men—has among other things proposed mechanical contrivances for the regulation of soaring.

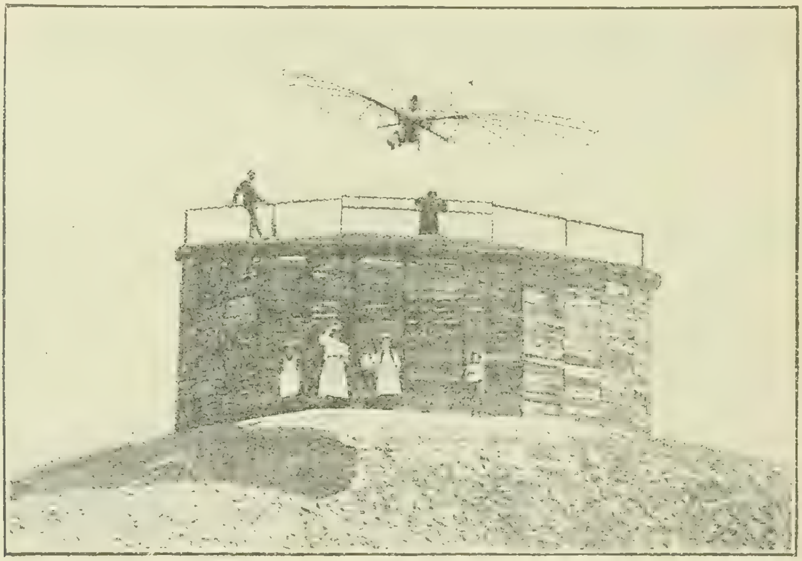


FIG. 1.

The apparatus is meant to descend from a captive balloon. By the application of ingenious methods the sailing surfaces (wings) are forced to retain their inclination. According to the report of Engineer M. Von Siegsfeld on the subject, no system has as yet been discovered that would promise sufficient security to any one sailing at a considerable elevation.

As desirable as it is that these investigations should discover safe automatic devices to give stability to soaring, it remains, on the other hand, doubtful whether the dangers attending such flights could even then be obviated. I am of the opinion that the evolution of the flying machine will be similar to that of the bicycle, which was not made in a day, and that this will not be either. Although in soaring the center of gravity may be placed below the center of pressure of the supporting air, it appears that even in this case, on account of the elasticity of the air itself, permanent stability could only be obtained by a constant and arbitrary correction of the position of the center of gravity. This

is performed by birds incessantly and it is in virtue of a perfect adaptation of the form of their wings to any aerial motion that their flight appears to us so sure, graceful, and beautiful.

In the same way a man can move through the air and have the general ability to guide his apparatus by a constant shifting of the center of gravity. Descent should not be at first tried from great elevations, for such a feat requires practice. In the beginning, the height should be moderate and the wings not too large, or the wind will soon show that it is not to be trifled with. In fact, under some circumstances, one may be swept off toward still higher regions, the descent from which might well be disastrous. It therefore seems best that the wings should not exceed from 8 to 10 square meters (somewhat over 80 to 100 square feet), or that the experiment should be conducted in any wind blowing more than 5 meters per second (nearly 1,000 feet a minute), which represents a gentle breeze. A good run against the wind, however, and a leap from a safe height of 2 or 3 meters may secure a flight of 15 or 20 meters.

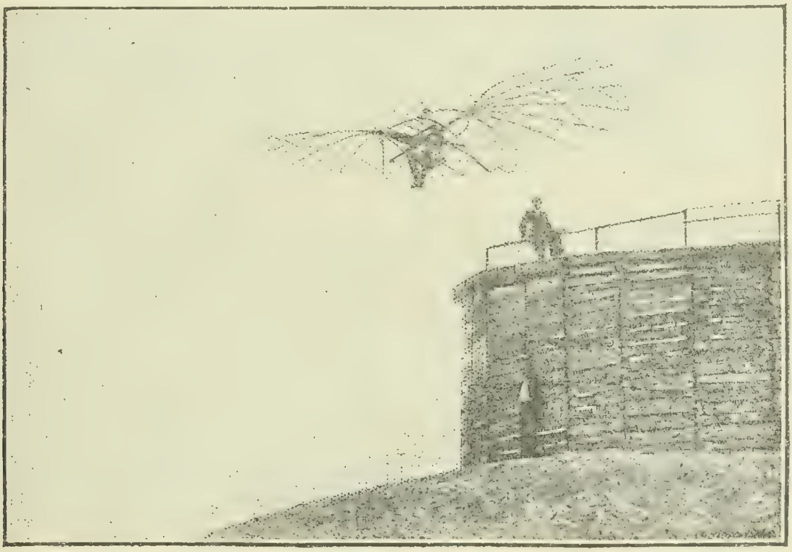


Fig. 2.

Continual practice will enable the experimenter to withstand a stronger breeze, to increase the surface of the wings to 15 square meters (160 square feet), and to start from a greater elevation, especially if there be a moderate slope beneath him with a soft, yielding surface. After becoming sufficiently expert to deviate from a straight line, the experimenter may enjoy the sensation of flying, but it is always a necessary condition that he should face the wind while descending, as the birds do. If then flight is attempted with the wind, it must be more rapid than the wind, or the result will be very apt to be a dangerous somersault at the time of coming to the ground, so that it is, on the whole, most advisable to follow the lessons of the birds, who ascend and descend against the wind.

I have been experimenting in this way for three years, and the constant progress made in the perfection of my machine and the increased security it gives has convinced me of the correctness of the plan. At all events, I think it best to perfect the soaring apparatus before attempting flight with movable wings.

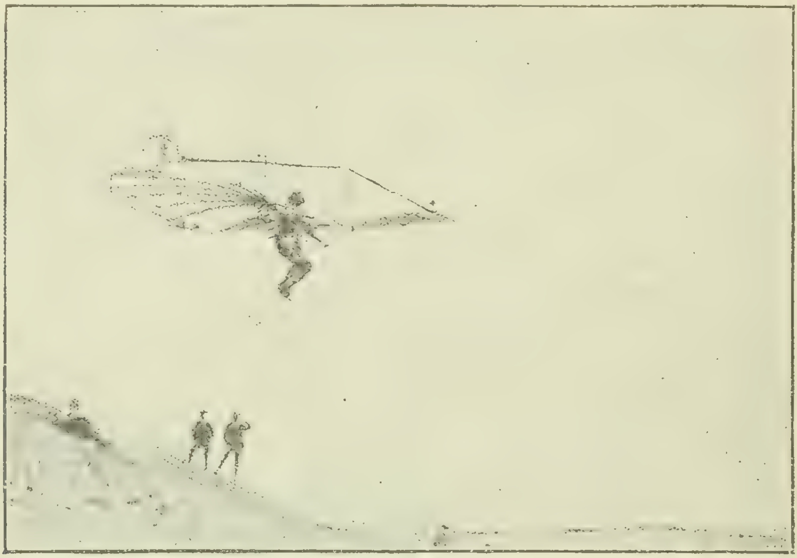


FIG. 3.

After numerous experiments from low elevations, I gradually ventured to increase the height, and for this purpose I erected a tower-like shed, which, while it gave me room to store my apparatus, enabled me to conduct my experiments from the roof. The illustrations, taken from instantaneous photographs, show one of my securely constructed machines for soaring and the various phases of a soaring experiment.

Figure 1 represents the first leap from the roof, the cut showing the front view of the apparatus, which in some respects resembles the spread wings of a bat, and folds up like those for convenience of storage and transportation. The frame is of willow, covered with sheeting; the entire area contains nearly 150 square feet, and the entire apparatus weighs about 45 pounds. The roof of the tower is rather over 30 feet above the surrounding level, and from this elevation, after sufficient practice, one may glide over a distance of over 50 yards at an angle of descent of from 10 to 15 degrees.

Figures 2, 3, 4 show the progess of the experiment. While flying freely in the air the proper angle of descent has to be regulated by shifting the center of gravity. Of course, the wind plays a very important part here, and it is only by long and constant practice that we can learn to make allowance for its irregularities and to steer the apparatus properly. The capriciousness of the wind may exert unequal pressure on the great expanse of wing, and then it may happen that one wing will be elevated higher than the other.

This is shown in fig. 5. In this case the equilibrium may be restored by a change in the center of gravity, which may be effected by extending the legs as far to the left as possible, and thus adding more weight

FIG. 4.

to the wing on that side. The two steering planes attached to the rear aid in enabling one to keep the face to the wind.

Figure 6 shows the simple manner of grasping the machine. There are no straps or buckles, and yet the connection is perfect. Each

FIG. 5.

arm rests on a cushion attached to the framework, the hands seize a cross-bar, and the remainder of the body hangs free.

My recent experiments have been made from hills having an elevation of about 250 feet and sloping uniformly every way at an angle of 10 to 15°. From the lower ridges I have already sailed a distance of over 250 yards. The great difficulty to be encountered in the endeavor to soar comes in learning to guide the flight, rather than in the difficulty of providing power to move the wings.

Progress in the mechanics of flying received at one time a severe check through the utterances of a high authority in physics. Starting with an erroneous hypothesis and putting too high a value on the amount of work required, he claimed that the maximum of possible flight had already been developed in the largest birds, and, as man represented about four times the heaviest of them, human flight was

FIG. 6.

to be discarded as an utter impossibility. Now, it must be admitted that the difficulties increase with the size of the flying individual; but flying itself is not the difficulty, for the largest flyers are at the same time the best flyers when they once get going in the air.

The object of this paper is to attempt to dispel old prejudices and to win new adherents for the problem in question. Even considered only as a physical exercise, the sport of flying would create one of the healthiest of all enjoyments and add one of the most effective remedies to the means now adopted for the conquest of those diseases which are incident to our modern culture.

PRACTICAL EXPERIMENTS IN SOARING.*

By Otto Lilienthal.

My own experiments in flying were begun with great caution. The first attempts were made from a grass plot in my own garden upon which, at a height of 1 meter from the ground, I had erected a spring-board, from which the leap with my sailing apparatus gave me an oblique descent through the air. After several hundred of these leaps I gradually increased the height of my board to 2½ meters, and from that elevation I could safely and without danger cross the entire grass plot. I then went to a hilly section, where leaps from gradually increased elevations added to my skill and suggested many improvements to my apparatus. The readers of *Prometheus* have already been informed of the selection of a piece of ground which enabled me to extend my flights over a distance of several hundred meters. The remainder of the summer since my last publication (in Nos. 204 and 205 of this journal) has sufficed to bring these experiments to a termination and to dispose of some important questions as to the possible results.

Indulging in subtile inquiries and theorizing does not promote our knowledge of flying, nor can the simple observation of natural flight, as useful as it may be, transform men into flying beings, although it may give us hints pointing towards the accomplishment of our purpose. We see buzzards rise skyward without any motion of their wings; we observe how the storks intermingle in the flock with outspread wings and in beautiful spirals; we see, high up in the air, the piratical falcon in quest of booty remain stationary in the wind for minutes at a time. We recognize every spot on his brownish plumage, but we do not perceive the least exertion of his wings to maintain his stationary position, and this small bird of prey is not in the least concerned at our presence. He reciprocates the protection secured for him since Brehm and other naturalists have pointed out his usefulness by undisturbedly precipitating himself to the grass before our eyes, and, seizing a grasshopper, we again see him meters above our heads without having detected the least flapping of his wings during the entire performance.

* Translated from *Prometheus*, No. 220, 1893, vol. v.

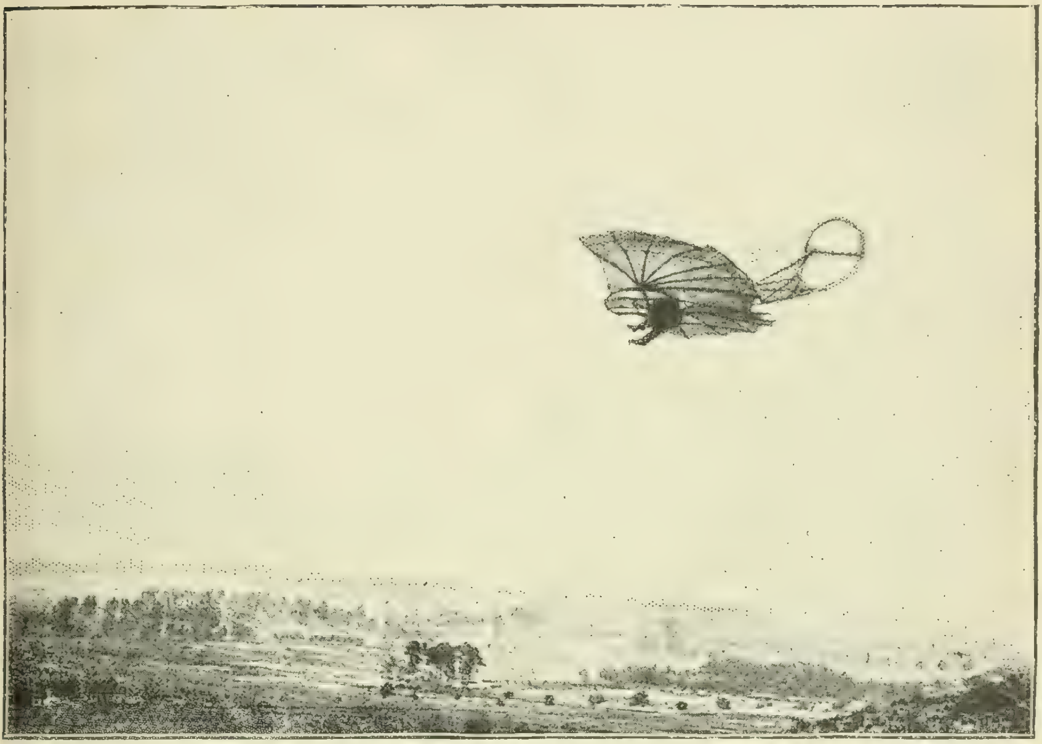
We notice that constant changes are going on in the force of the wind, but the falcon does not alter his position by a single inch, although having already begun devouring his prey, he can give but divided attention to his flight. Now he bends his head downward and backward, so that the world below must appear to him inverted, and evidently enjoys eating the insect as his talons leisurely pluck it to pieces. In the position in mid-air (which is maintained even during this employment) he appears like an automaton rooted in the wind. Just the faintest balancing motion, apparently serving to compensate for the irregularities of the wind, is perceptible in the extreme points of his wings, which are slightly inclined backwards.

This poise of the falcon in mid air, which appears to us as a defiance to the law of gravity, may be considered not only the most remarkable, but also the most instructive example of flight.

In observing the majestic, circular soaring of other aërial travellers, one can readily believe that these skillful wing artists understand how to profit by the periodic currents of the air, and in describing spirals instinctively transform the force of the opposing current of air into lifting or suspensive power; but when the bird, without the least movement of his wings, remains stationary in one point of the sky, we are led to infer the existence of a peculiar form of surface which may be held suspended by the application of a uniformly moving wind.

While the existence of this possibility may be demonstrated by elementary experiments, this does not discover the secret of soaring, and though nature conclusively demonstrates that it can not be the want of power that prevents our flying, that knowledge alone does not provide us with wings. Furthermore, while nature points out how it is done, that does not necessarily imply that there may not be found other ways or means of doing it. However we may theorize on the subject, without a practical application of the theory, things will remain unchanged and our flight will only be in imagination or in dreams.

My experiments, then, should form the transition, the first step from theory to practice. Like others, I too have, in the beginning, attempted using machines with movable wings, but this does not apparently aid in the development of an art of flight. The mark is too high and not immediately attainable, and one's ambition should be fully satisfied by withstanding the wind with wings of the size adapted to flying men. Each flight demands a rising from the ground and a landing; the former is as difficult as the latter is dangerous, and regardless of the most ingeniously constructed apparatus, the art of both will have to be acquired just as the child learns to stand and to walk. Anyone desirous of exposing himself unnecessarily to danger and of ruining in a few seconds the carefully constructed apparatus need only expose his machine to the wind without having familiarized himself with its management, and he will soon know what it means to control an appa-



PRACTICAL EXPERIMENTS IN SOARING.
(Reproduced from "Prometheus.")

ratus of from 10 to 15 square meters in area, where other people can but with difficulty manage an open umbrella.

To all those who, by their own experience or otherwise, can form a correct idea of the difficulties that present themselves, the instantaneous photographs by Mr. Alexander Krajewsky, accompanying this paper, may be of interest.

In continuation of my formerly published experiments, I endeavor with every new trial to gain more complete control over the wind, and without disregarding any necessary precaution I have already succeeded in at least temporarily retaining a uniform level and even in remaining stationary in the wind for a few seconds. The simplicity of my flying machine, which is controlled by shifting the center of gravity, has compelled me to avoid strong breezes, which however might presumably have aided in securing a stationary position. During my continued flights, however, I have been at times surprised by a sudden increase in the force of the wind which either carried me upward almost perpendicularly or supported me in a stationary position for a few seconds to the great delight of the spectators.

The freedom from accidents in these apparently daring attempts may be considered proof that the apparatus already described offers ample security in carrying out my plan of investigation.

To those who, from a modest beginning and with gradually increased extent and elevation of flight have gained full control over the apparatus, it is not in the least dangerous to cross deep and broad ravines.

It is a difficult task to convey to one who has never enjoyed aerial flight a clear perception of the exhilerating pleasure of this elastic motion. The elevation above the ground loses its terror, because we have learned by experience what sure dependence may be placed upon the buoyancy of the air. Gradual increase of the extent of these lofty leaps accustoms the eye to look unconcernedly upon the landscape below. To the mountain climber the uncomfortable sensation experienced in trusting his foot into the slippery notch cut in the ice or to a treacherous rubble above deep abysses, with other dangers of the most terrifying nature, may often tend to lessen the enjoyment of the magnificent scenery. The dizziness caused by this, however, has nothing in common with the sensation experienced by him who trusts himself to the air; for the air demonstrates its buoyancy in not only separating him from the depth below, but also in keeping him suspended over it. Resting upon the broad wings of a well-tested flying machine, which, yielding to the least pressure of the body, obeys our directions; surrounded by air and supported only by the wind, a feeling of absolute safety soon overcomes that of danger.

One who has already practiced straight flights for some time will naturally endeavor to next guide his apparatus in a lateral direction, and indeed there is nothing easier than the guiding of the aerodrome, which is accomplished by shifting the center of gravity. The steering

blades have nothing to do with this, their function being to keep the machine facing the wind.

Plate XIII, fig. 1, illustrates such a serpentine flight. I started from a hill to the right, the base of which is still visible in the figure, and soared toward the plain below in a somewhat circuitous path. The photograph was taken at the moment when I had almost turned my back to the plain. The view shown in Plate XIII, fig. 2, was taken at a time when I was lifted and carried upward by a suddenly increasing current, which impeded progress and rendered me absolutely stationary.

In Plate XIV, flights are represented in geometric perspective. The lowest dotted line, *d e*, was described during a calm. Even the expert flyer must descend during a calm at an angle of from 9° to 10°. The run began upon the top of the hill, near *a*; at *b* I left firm ground and endeavored to glide along the mountain slope, placing the wings at *c* at such an angle that the pressure of the wind, *L*, would not only support the machine, but also carry it forward. This increased the velocity sufficiently to enter at *d* into the line of stable flight. Such a maneuver is necessary, because a velocity of 9 meters per second is required for a flight in a calm, while but 6 meters were obtained by the run. At *e* the ground has almost been reached, and by raising the wings slightly in front the momentum is diminished and a landing effected without serious jar.

The second line, *c f*, shows a flight in a moderate breeze, in which the proper position with a downward inclination of 6° had been assumed immediately upon starting.

Flight against the wind is slower. The distance to be accomplished may be extended by a carefully determined and properly maintained inclination of the wings; in fact, by careful observation of this the soaring may be extended over a distance equal to ten times the height of the starting point.

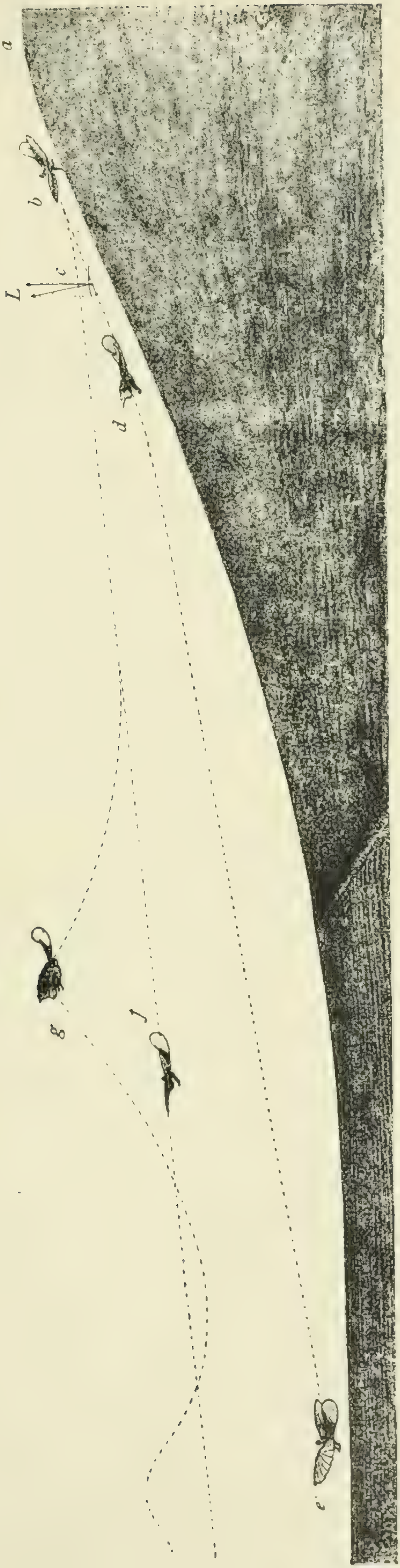
During a strong breeze a sinuous line of flight results from the temporary support given by the wind at times. This is shown in the line *b g*, though such experiments should be undertaken only by one fully familiar with the management of the apparatus. The indefinable pleasure however experienced in soaring high up in the air, rocking above sunny slopes without jar or noise, accompanied only by the æolian music issuing from the wires of the apparatus, is well worth the labor given to the task of becoming an expert.

It does not seem at all impossible that the continuance of such flights may lead to free, continuous sailing in agitated air.

The results of our present experiments already furnish an indication of the degree of mechanical energy that must be added to that involved in oblique soaring to enable us to gain independent horizontal flight.

The solution of this problem,* however, would exceed the purposes of the present article, and I content myself by stating that the condi-

* *Zeitschrift fur Luftschiffahrt und Physik der Atmosphäre,* November, 1893.



PRACTICAL EXPERIMENTS IN SOARING.
(Reproduced from "Prometheus.")

tions of a motor can easily be met, supposing that the propelling mechanism has been properly chosen, and that extraordinary lightness is not even essential.

The interests of the professional flight-essayer demand further experiments in practical flight and the gain of further efficiency. But even to those who only desire to utilize, as a means of sport, the results already obtained, opportunities are offered to promote the interest of the problem of flight and the way for a more ready prosecution of the subject.

The time has passed when every person harboring thoughts of aerial flight can at once be pronounced a charlatan. If we may hope that our aeronautic publications are eventually to be taken seriously by the majority of those skilled in allied subjects, it is important at the outside to awaken the interest of those whose natural concern this great problem should be, but who now shrug their shoulders. We shall then at least be able to show some practical results, and towards these ends we here take the first step.

PHENOMENA CONNECTED WITH CLOUDY CONDENSATION.*

By JOHN AITKEN, F. R. S.

In the first part of this communication I intend giving the results of an investigation into the phenomena connected with the cloudy condensation produced when a jet of steam mixes with ordinary air, with special reference to the marked change which takes place in the appearance of the jet by electrification and other causes. In the second part will be given the results of an investigation into certain color phenomena, which can be produced when the condensation is made to take place under certain conditions, and it is thought that these experimental color phenomena, if they do not give the explanation of a "green sun," at least enable us to reproduce it artificially with the materials existing in our atmosphere.

PART I.—STEAM JETS.

When a jet of steam escapes into the air condensation at once ensues by the expansion and the mixing of the steam with the cold air. The result is the jet becomes distinctly visible by the light reflected by the minute drops of water carried along in the mixed gases and vapor. At first sight there is little that is interesting in the changes then taking place. The subject has therefore attracted but little attention and has been but little studied. This is evident from the great interest that has been taken in the change produced in the appearance of the jet when it is electrified, yet I hope to be able to show that this is only one of a number of causes which alter the appearance of the condensing steam.

R. Helmholtz was the first to show that when an ordinary jet of steam is electrified there is a marked increase in the density of the condensation. The effect of the electricity is certainly very remarkable. The instant the jet is electrified it at once changes and becomes much denser, and the condensed particles also become visible much closer up to the nozzle from which the steam is escaping. For the conven-

* From the *Proceedings of the Royal Society*, April 28, 1892; vol. LI, pp. 403–439.

ience of description we shall call this second form of condensation *dense condensation*, while that usually observed we shall call *ordinary condensation*. Not that there is any hard and fast line between these two forms, as the one may be made to change by imperceptible degrees into the other. All that is meant is that the one is dense compared with the other.

One result of this investigation is that in addition to electrification of the jet, there are four other ways in which the ordinary condensation may be changed into the dense form. These five ways of changing the ordinary into the dense form of condensation are:

1. Electrification of the jet.
2. An increase in the number of dust nuclei.
3. Cold or low temperature of the air.
4. High pressure of the steam.
5. Obstructions in front of the jet and rough or irregular nozzles.

We shall now describe some experiments to illustrate each of these different ways of causing the ordinary condensation to change and take the dense form. In the experiments to be described, the steam was generally generated in a copper boiler, which could be pressed up to fully one atmosphere. The nozzle from which the steam escaped was placed at some distance from the boiler to prevent the hot gases influencing the jet. The steam was conveyed by means of a metal pipe to the nozzle, and a water trap was placed near the end of this pipe to prevent the irregularities which would be produced if the water condensed in the pipe were allowed to issue from the nozzle. The nozzle generally used was made of brass, carefully bored to a diameter of 1^{mm}., the diameter of the bore widening inwards, while the outside of the nozzle was turned to a fine edge in front. With this apparatus most of the experiments were made, but occasionally glass vessels and nozzles were used, as well as vessels and nozzles of other materials, but with no marked difference in the results.

1. *Electrification.*—In the experiments with electricity only steam of a low pressure should be used. The reason of this will be understood from what follows under division 4. In these experiments slight electrification was used, as only an old-fashioned cylinder electrical machine was available for the purpose, and in the damp atmosphere produced by the steam jet the electrification was only capable of giving a spark of about 1^{cm}. or generally less.

The necessary condition for the electricity producing any effect on the jet is that the particles in the jet be electrified either by direct discharge or by an induction discharge. The mere presence of an electrified body near the jet has no influence whatever. In order that it may have an effect, the electrified body must terminate in a point placed near the jet, and the potential must be great enough to cause a discharge of the electricity to the jet. When this takes place, the jet

at once becomes dense and remains in that condition while the discharge continues. The electrified body may however electrify the jet by induction. If for instance the electrified body be a sphere, and the nozzle from which the steam is issuing be pointed, the electricity discharged by the nozzle will electrify the particles, and the condensation becomes dense. But if the nozzle be not pointed, then the presence of the electrified body produces no change, as there is no discharge of electricity. But if now we hold a needle, or other pointed conductor near the jet issuing from the rounded nozzle, it at once becomes dense by the induction discharge from the point. In place of a point in the last experiment, we may use a flame; in fact, we may use any influence which will enable the electrified body to electrify the particles in the jet.

Another way of making this experiment is to insulate the boiler, and electrify it. If the nozzle be pointed, the jet becomes dense on electrification; but if it be rounded, the electrification has no effect. If, however, we bring a needle or a flame near the rounded nozzle, the jet becomes dense. To get no effect from the electrification it is necessary that the nozzle be a ball of some size, the orifice through which the steam issues being, of course, the same diameter as that of the pointed jet.

The effect of the electrification has been studied by R. Helmholtz and by Mr. Shelford Bidwell,* but neither of them seems to be satisfied with any explanation offered. Mr. Bidwell, from a spectroscopic examination of the light transmitted through the jet under the two conditions, came to the conclusion that in the dense condition the particles were larger than in the ordinary form of condensation; and he thinks that the increase in size is due to the electricity causing the small drops of water to coalesce and form larger drops. In support of this explanation, he quotes Lord Rayleigh's experiments on the coalescence of drops in water jets while under the influence of electricity. As Mr. Bidwell does not put forth this opinion as final, there is less reason for hesitation in stating that the conclusion I have come to is diametrically opposed to Mr. Bidwell's.

There seems to be no doubt that electricity will act on these very small drops of water in the same way as it acts on the drops in a jet of water. That its action is similar is easily proved by the following experiment with mist drops: Take a small open vessel full of hot water—it is better to color the water nearly black for convenience of observation—a cup of tea without cream does very well for the purpose. Place the cup on a table between the window and the observer. On now looking at the cup from such a position that no bright light is reflected from the surface of the liquid, there will be seen what looks like scum on the surface of the tea. That scum is, however, only a multitude of small mist-drops, which have condensed out of the rising steam and

* *L. E. D. Phil. Mag.*, February, 1890, vol. XXIX, pp. 158–162.

have fallen on the surface of the liquid, where they are seen floating. If now we take a piece of brown paper, or any convenient material, and rub it slightly and hold it over the cup, the "scum" will disappear at once, and be replaced by other drops when the electrified body is removed. As in Lord Rayleigh's experiments, a very feeble electrification is sufficient to cause the absorption of the drops into the body of the liquid. It is therefore not because there is supposed to be any difference in the action of electricity on large and on very small drops that a different conclusion from Mr. Bidwell's has been arrived at, but because all the experiments to be described point to the conclusion that the dense form of condensation is not due to an increase in the size of the drops, but to an increase in the number, accompanied of course by a diminution in the size.

We may suppose the following to be something like the manner in which the electricity acts on the jet: In a steam jet the rapid movements of the drops give rise to frequent collisions, and these result in the coalescence of many of the drops, so that each drop in ordinary condensation is made up of a number; but when the jet is electrified, the electrification prevents the particles coming into contact, as they repel each other, and the consequence is we have a greater number of particles in a dense and electrified jet than in an ordinary one.

Lord Rayleigh's experiments on the action of electricity on water jets support this view. He has shown that in order to produce coalescence the electrification must be very slight, and he also points out that the coalescence does not seem to be so much due to electrification as to a difference of electrification, which would appear to cause a discharge of electricity to take place between the drops, which ruptures the films, so causing contact. Further, he has shown that when the electrification is strong and the conditions are such that the drops become electrified, the effect is diametrically the opposite, and instead of coalescence the particles now scatter far more than the unelectrified drops. Now from the conditions of the experiments with electrified steam jets it is evident that the drops are electrified and are in the same condition as the electrified scattering water jet. We are therefore entitled to expect that the electricity will prevent and not aid the coalescence of the small drops in the steam jet.

Other considerations also point to the increase in the density of the jet being due to an increase, and not to a diminution in the number of drops. We know that if we blow steam into air, that the fewer dust nuclei there are in the air the thinner is the condensation; and when the dust is nearly all out of the air, only a fine rain falls which can scarcely be detected by the unaided eye. Further, the evidence from condensation produced by expanding moist air points to the same conclusion, namely, that the more dust particles there are in the air the denser is the condensation when cooled by expansion, and the purer

the air is the thinner is the cloud.* These experiments all point to the conclusion that the dense form of condensation is due to a large number of water drops, and the thinner form to a smaller number, though of greater individual size. The only condition under which it seems probable that the increase in number will not give rise to increase in density is when the particles are so small that they are unable to reflect waves of any color of light. So far as has yet been observed, this never happens. However slight the amount of expansion, the greater number of particles always gives the denser form of condensation.

The action of the electricity on the jet does not appear to be anything positive; it rather seems to prevent something which takes place under ordinary conditions. For instance, electricity has no effect in thickening the cloud of so-called steam rising from a hot and wet surface. The electrically driven current of air from a point when directed to the steaming surface has no effect whatever on the density of the condensation. Nor has electricity any effect on the steam rising from an open vessel. The small drops of water under these conditions move but slowly, and there is but little tendency for them to come into collision with each other. There are therefore few collisions for the electricity to prevent, and little or no thickening is produced by electrification under those conditions. Further on we shall have frequent opportunities of seeing that the dense form of condensation is the result of an increase in the number of particles, and that whatever gives rise to an increase in the number causes an increase in the density.

When the jet is electrified and becomes dense, it has been noticed by others that it emits at the same time a peculiar sound, and I find that whenever the jet becomes dense, from whatever cause, it begins "to speak." But when the density is due to electrification, the sound is slightly different from the sound emitted when dense from any of the other causes. When dense from cause other than electrification, the sound is similar to that produced by the jet striking an obstruction; but when electrified, the sound is a combination of this sound with another due to the discharge of the electricity, and this second sound depends on the manner in which the electric discharge takes place. If the discharging point is not sharp, and the potential is just sufficient to cause discharge, then the discharge is not continuous, but takes place at short intervals. It becomes, in fact, a series of disruptive discharges, and gives rise to a fluttering noise. This fluttering sound is greatly increased if the point terminates in a small ball of about 1 millimeter diameter, and it is entirely abolished if we use a very sharp point, or better, a flame. The discharge with either the very sharp point or the flame is perfectly continuous, and nothing but the slight hissing that accompanies all dense forms of condensation is heard when the jet is electrified.

* *Trans. Roy. Soc., Edinburgh*, vol. XXX, Part I, pp. 340.

It has generally been stated that the effect of the electrification is sudden and marked, that whenever the jet is electrified it at once becomes very dense. This however is due to the manner in which the jet has generally been electrified. Some degree of potential is necessary to produce a discharge from the point, and whenever the potential is high enough to cause this, it is sufficient to charge the drops high enough to give rise to a very dense condensation. But if we make the discharging point extremely fine, or assist the discharge by means of a flame, then we may begin with electricity of a very low potential, and the increase in the density may be made to begin by almost imperceptible degrees and to increase slowly to the dense form by gradually increasing the potential.

We shall for the present leave the question of the effect of the ordinary and the dense forms of condensation on the light transmitted through them, as it will be better discussed after we have considered all the ways in which the jet may be made dense, and we shall now pass on to consider the second of those given in our list.

2. *An increase in the number of dust nuclei.*—It has been noticed by previous observers that a flame brought near the jet tended to make the condensation dense; but, in describing the experiments, a confusion has generally been made between the flame and the products of the combustion taking place in the flame. So far as I have been able to observe, flame has no effect on the density of condensation. Neither a luminous flame nor the flame of a Bunsen burner has any effect so long as the products of combustion are kept away from the jet. But if the products are drawn into the jet, they have a very marked effect either in increasing or decreasing the density. If the flame is near and the gases are hot, they make the jet nearly invisible, but if the gases are cooled or are not in great quantity, then they make the jet as dense as if it were electrified. The simplest way of studying this latter effect is to bring the products of combustion to the jet by means of a metal tube 2 or 3 centimeters in diameter, and about half a meter long. A small flame about half a centimeter high, placed below the level of the jet, is used. One end of the tube is kept over the flame while the other can be brought near the nozzle. It will be found that when brought into that position the jet will at once become dense, and when it is removed it will return to its ordinary condition, and become dense again with every return of the impure gases.

The increase in density in this case is due to the greater number of dust particles in the gases offering a greater number of nuclei for condensation, and the result is a great increase in the number of water particles and consequent thickening of the condensation, a result which, as has already been stated, the author proved some years ago.

The change in the appearance of the jet when the products of com-

bustion are brought to it is exactly the same as that produced by electrification. The whole jet becomes dense, the condensed particles are visible nearly up to the nozzle, and the jet makes the same sound as when electrified by silent discharge, and further, electricity of the potential used does not make it any denser.

It seems probable that the very great number of dust particles in the products of combustion act in two ways: first, by supplying a great number of nuclei, and second, as the number is greater the drops will be smaller, and, on account of their small size, they will have less independent motion, as they will be more guided by the gases than larger drops; there will therefore be fewer collisions, and not the same tendency to the diminution of numbers by the coalescence of a number of drops into one. It may be because of the small number of the collisions when the particles are small that electricity has little or no effect on the jet when it is dense from a large supply of nuclei. It is possible that some of the increased density produced by the products of combustion may be due to the slight electrification of gases from flames. But as the electrification from this source is very slight, its effects will be extremely feeble indeed when the dust particles are developed to the size of drops, so that the electricity from this source is not likely to have much effect.

3. *Cold or low temperature of the air.*—We now come to the third cause of the dense form of condensation, namely, low temperature of the air. At first sight it may appear that the above statement contains an already well known fact. But while in a certain sense this is so, yet there is one point of great importance, which (so far as I am aware) has not previously been observed. If we were asked to state what is the effect of the temperature of the air on condensation of the jet, we probably would say that when the temperature of the air is high the condensation is very transparent, owing to there being less vapor condensed and to its rapid re-evaporation: and that when the temperature became lower and lower the jet gradually thickens as the temperature falls, owing to the greater amount of condensation caused by the colder air. Such a description is far from a full statement of the facts regarding the changes in appearance with the fall in temperature, and the explanation is correspondingly faulty. There is an influence at work in the condensing jet which, though due to temperature, is of far more importance than the effect of the temperature on the amount of steam condensed.

When I first encountered this new influence it greatly puzzled me. I had opened the window of the room where the experiments were being made, and when the fresh air came in the jet began to behave itself in a most uncertain way. At one moment it was quite steady ordinary condensation, and the next it would conduct itself as if electrically excited. Even after the window was closed it continued to

change from the ordinary to the dense form of condensation in a puzzling way. It was first thought that outer air might be electrified, and tests were accordingly made to see if this were the case. These tests showed that if it were electrified it could be so but slightly, as it did not affect a gold-leaf electroscope, which it would require to have done to have produced the increased density observed in the steam jet. Electricity as the solution of the difficulty had, therefore, to be abandoned. The only other influence I could think of as likely to cause the effect was some unknown effect of cold. I therefore took the metal tube which had been used in a previous experiment for conveying the products of combustion from the flame of the jet and cooled it. On now presenting one end of this cold tube to the jet it at once responded, and the condensation became as dense as if a flame had been at the other end of the tube, or as if the jet had been electrified.

This effect was all the more surprising since there was no great difference between the temperature of the air in the tube and that of the room,—not more than 10° F. Some experiments were therefore made to find out the temperature at which this change takes place, and to see if it was as sudden as it appeard to be. The jet was supplied with air cooled in a pipe, which was surrounded with water for regulating the temperature of the air. The steam nozzle was placed just inside one end of the pipe and pointing outwards, so that the jet drew its supply of air out of the tube. No very satisfactory results were got with this apparatus. It may however be mentioned that when the air was cooled the jet somewhat suddenly became dense, and again became ordinary when the temperature was slightly raised; but with the apparatus it was difficult to say what the temperature of the air really was when the change took place.

Another method of studying the effect of temperature on the density was tried with fair success. The nozzle was fitted to the end of a horizontal pipe; the nozzle also being pointed horizontally. For this experiment a morning was selected when the temperature of the room was low. When the experiments began the temperature was 40° F. At this temperature the jet was always dense, and neither electrification nor the products of combustion increased its density. The room was now slowly heated, and the jet watched while the temperature rose. Up to a temperature of 46° no change took place, and the jet was not made denser by electricity nor by the products of combustion. But when the temperature rose to 47° the jet began to show signs of clearing. The clearing did not however take place regularly; one moment the jet was dense and the next it was ordinary. These fluctuations would be due to the unequal temperature of the air coming to the jet. At one moment the air would be the air of the temperature of the room; the next would be this air slightly heated by the metal pipe and nozzle. So that when the jet drew its supply of air horizontally its condensation was ordinary, and when the air currents in the room

prevented this heated air from coming to the jet its condensation was dense.

A slight alteration was then made in the arrangement. The jet was now directed downward at the end of the horizontal pipe. By this means the air heated on the pipe and nozzle was prevented from mixing with the jet. The jet was directed at a small angle from the vertical to prevent the hot air and vapor of the jet rising to the nozzle. With this arrangement the following was the result: Up to a temperature of 46° the condensation was dense, and neither electricity nor the products of combustion had any effect on the density; but when the temperature rose to about 47° electrification began to have just a perceptible effect in increasing the density. At about 48° the electricity had an easily observed effect, and the products of combustion also had a slight effect. At a temperature of 50° the jet had become decidedly thinner, and both electricity and the products of combustion had a decided effect in increasing its density. When the temperature rose to 55° the jet lost its dense appearance, and both electricity and the products of combustion had a very marked effect.

It might be thought that by observing a steam jet in the open air we could tell if the temperature of the air was above or below a certain point. This however can only be done in a very rough way, as the conditions are variable and not within our knowledge. We would require to know the pressure of the steam and the degree to which the air was heated by the pipe. In a general way it may be stated that in the open air a steam jet looks dense if the temperature be below 50°, and ordinary if above 55°. But it is often difficult to say what is ordinary and what is dense condensation, unless the observations are made carefully and by examining how close to the nozzle the particles are visible. Of course, if we could electrify the jet or supply it with the products of combustion, we could tell whenever the temperature was over or under 47°.

The sudden alteration in the appearance of the jet when supplied with air at a temperature of 46° points to some change in the influences in action in the condensing jet. The great increase in density can not be due to an increase in the amount of vapor condensed, as the fall in the temperature is slight. Further, it will be observed that the jet has ceased to be influenced by electricity and by the products of combustion. The only explanation I could think of was that at the temperature of the mixed cold air and steam some alteration had taken place in the surface films of the water drops. The jet looked as if something came into action at that temperature which prevented the drops coalescing when they came into collision, or what would amount to the same thing, that at high temperatures there was no tendency for the drops to recoil after impact, and that when the temperature fell this property made its appearance and prevented contact in the same way as we have supposed the electrification does.

The simplest way of testing this explanation was to repeat Lord Rayleigh's experiment with water jets, but in place of cold water using hot. The result is, the experiment entirely confirms this explanation. So long as the water in the jet is above a certain temperature there is no scattering whatever, but perfect coalescence of the drops on contact. As a consequence the jet is not influenced in the slightest degree by the presence of an electrified body. It is only after the temperature falls below a certain point that the scattering commences and electricity begins to have an influence.

This experiment shows that it is only when the drops are below a certain temperature that their surface films act in the way we are accustomed to observe at ordinary temperatures—that is, repel each other; and that when the temperature is high there is an entire change, and the surface films no longer repel, but coalescence of the drops takes place at each collision. It will be noticed that the point here is, not the appearance of any new influence with the low temperature, as the films are then in the condition with which we are acquainted; it is at the high temperature that the new condition comes into action and the films lose the resisting action with which we are acquainted.

Now, it seems extremely probable that the change in the appearance of the steam jet when the temperature of the air is lowered is due to the temperature of the jet falling to the temperature at which this repulsive action makes its appearance.

There is however an experimental link wanting to bind these two phenomena together, which I have desired to complete, but unfortunately experimental difficulties stopped the way. The link wanting is some experimental proof that the jet gets dense at the same temperature that the water jet begins to scatter. On attempting to take the temperature of the jet difficulties presented themselves. If it is to be taken with a thermometer, where is it to be placed? A very slight change in the position of the bulb of a thermometer placed in the jet gives a different reading. It does not matter whether the change be made nearer or further from the center of the jet or nearer or further from the nozzle. In all cases a very slight change gives a considerable difference of temperature. It may however be stated that when the bulb was placed in the center of the jet and near the nozzle it showed a temperature of about 130°, but that figure can only be looked upon as a very rough approximation to the true temperature.

One or two attempts were however made to find the temperature at which water films ceased to have any repulsive action. This was done by means of a small water jet, and it was found that above 155° there was no scattering. It was not till the temperature fell below that point that electrification had any effect. This was the temperature of the drops themselves, not of the supply for the jet, and it may not be quite accurate, as the drops tend to cool very quickly. Another method of finding this temperature was to observe the highest temperature at

which the mist drops floated on water in the experiment previously described. This method is not very satisfactory, on account of the difficulty of seeing the drops when the temperature is high, owing to the amount of condensed steam hanging over the water. It is also difficult to keep the surface of the water clean. The tests by this method gave a temperature considerably higher than that given by the water jet. Neither of these methods however, promises to give satisfactory information on this point; but, if it were desired, the effect of temperature on the contact of films could be studied in a more accurate way.

It is difficult to imagine any sudden change in the action of the films at or about the temperatures indicated. There is no corresponding change, so far as I am aware, in the surface tension. We might picture to ourselves the change to be brought about by the alteration which takes place in the intervening gases. When the drops are cold the bounding surfaces are water and air with very little vapor in it. And perhaps we may be permitted to assume that the surface film has a layer of air condensed on it, and it may be this condensed layer of air which prevents contact when the drops come into collision. But when the temperature is high the conditions are changed. The bounding surfaces are now water and air with a large amount of vapor in it, and this vapor may play an important part in bringing about the contact, by the violent interchange of water molecules taking place at the surfaces of the films and weakening the condensed films of air. If this explanation be correct, then there is really no sudden change in the action of the films, and the repulsion is a gradually increasing one with fall of temperature. Though a somewhat sudden change in the appearance of this jet might seem to indicate a sudden change in the action of the films, yet the change may be really a slowly increasing one, and the sudden change in the appearance of the jet may be due to the repulsion rising to such an amount that the very small particles are prevented from coalescing. If the relative temperatures given for the coalescence of water drops and mist drops be correct, then the gradual rise in the repulsion with fall in temperature may be the explanation of why the drops in a water jet coalesce at a lower temperature than the mist drops on the surface of water. The water may require to be cooled to a lower temperature before the repulsion is sufficient to prevent the heavier drops from coalescing, while the less repulsion at the higher temperature may be sufficient to prevent the lighter mist drops from coming into contact. The same explanation helps to account for the increased density produced by increasing the dust particles, a less repulsion being sufficient to protect the excessively small drops.

The explanations we have here offered of the action of electricity and low temperature are in complete agreement. In ordinary condensation when the temperature of the air is high there is no surface repulsion, owing to the high temperature in the jet, and many of the particles coalesce on collision with each other; but when the drops are electri-

fied these mutual repulsions prevent contact, and the result is a large increase in the number of drops and a dense form of condensation. On the other hand, when the temperature is lowered, surface film repulsion comes into action, contact is prevented, and the drops do not coalesce on collision, and the result is exactly the same as if they were electrified.

In these remarks no reference has been made to the effect of the dryness of the air on the density of the condensation. It seems probable that the relative humidity of the air will have a less influence on the density than on the duration of the jet; that is, the length of time the drops take to evaporate.

4. High pressure of the steam.—The fourth cause of the dense form of condensation is high pressure of the steam. If the temperature be below 46° the condensation is dense at all pressures, but as the temperature rises, the condensation ceases to be dense if the pressure *of the steam be low*. But if we now raise the pressure, the jet again becomes dense, and the higher the temperature of the air the higher the pressure must be raised to produce the dense form of condensation. The action of the high pressure in producing the dense condensation is more complex than any of the previous causes. It acts, first, by the more rapid movements of the jet mixing a larger amount of air with the steam, by which means a greater number of dust nuclei are taken into the jet; and, second, a lower temperature is also produced, which probably brings the temperature of the drops low enough for the repulsive action of the films to come into play. But in addition to the effects of a greater amount of air being mixed with the steam, a third action here comes into play. Owing to the violent rush of steam, the condensation takes place more rapidly; and it has been found that the more rapidly the condensation is effected the greater is the number of particles formed. If the condensation takes place slowly, a much less number of nuclei are sufficient to relieve the super-saturation, as there is time for the movements of the water molecules to take place; but if the rate of condensation be forced, then the tension of super-saturation compels a great many more dust particles to become centers of condensation. The result of this is, that with two samples of the same mixture of air and steam, if one of them be condensed slowly the clouding is thin, while if the other be condensed quickly it is thick. This action will come into play in the steam issuing at high pressure, when the steam is rapidly expanded, cooled, and then mixed with cold air.

The increased density produced by increase of pressure also takes place somewhat suddenly, though not quite so suddenly as when the density is produced by the other causes. The jet first gradually thickens as the pressure rises, then a stage is arrived at when it somewhat suddenly becomes dense. When this last stage is arrived at, neither electrification nor the products of combustion cause any increase in the density. The first thickening is probably the result of the quickening of the condensation and increase in the number of dust nuclei;

and the sudden increase in density is probably due to the temperature falling low enough for the films of the drops to have a repulsive action, sufficient to prevent them from coalescing.

5. *Rough nozzles and obstructions in front of jets.*—If we use a nozzle of irregular form, or having roughened edges, it is found that it gives a dense condensation at a lower pressure than a nozzle of circular section with smooth bore and thin, even edges. This is owing to the irregularities in the nozzle, producing eddies in the jet, and mixing a greater amount of air with the steam, so cooling it more and supplying it with a greater number of nuclei. It, in fact, acts in the same direction as increase of pressure, and aids pressure in producing its results with a less velocity of steam.

An obstruction in front of the jet acts in a similar manner, if we have a jet of steam of such a pressure that at the temperature of the air it gives only the ordinary form of condensation. If now we place an obstruction in front of the jet so as to produce eddies, the condensation at once becomes dense. Wind has also a somewhat similar effect. The reason of the increased density in these cases is the same as for the jets issuing from irregular nozzles. They all assist the pressure in intensifying the density of the condensation by lowering the temperature of the jet, increasing the number of nuclei and quickening the rate of condensation.

The seat of the sensitiveness of the jet.—The seat of maximum sensitiveness to all influences tending to change the condensation from ordinary to dense is near the origin of the jet close to the nozzle. The different influences, however, affect the jet to different distances from its origin. The most limited in the range of its action is cold, which only produces the dense condensation when it acts near the nozzle, whereas some of the other influences have some effect, though a gradually decreasing one, to a distance of 2 or 3 centimeters from the nozzle.

The following experiment illustrates the limited range of the action of cold: A piece of ice about 2 centimeters thick was selected, and a small hole bored through it. The ice was then held so the steam jet passed through the opening. While the ice was held at a distance of 1 centimeter from the nozzle, almost no effect was produced, though much cold air from the ice was mixing with the jet. But when the ice was brought nearer the origin of the jet, so that the nozzle almost entered the plane of the ice, the dense condensation immediately appeared.

The range of sensitiveness of the jet to change of condensation by obstractions is also very limited. It is only when the obstruction acts near the nozzle that its effect is great. For instance, the blade of the knife resting on the nozzle with its back or edge pointing in the direction of the jet, and depressed so as to deflect the jet slightly, causes the jet to become very dense. But if the knife acts on the jet at a distance of only 1 centimeter from the nozzle very little increase in density is produced.

The range of action of electricity is much greater than that of cold or obstruction. If we screen the nozzle and the part of the jet near it from electrification, it will be found that at a distance of 3 or 4 centimeters a slight increase in density can be produced with the electrification used in these experiments.

The action of the products of combustion has a range similar to that of electricity. If the products are supplied to the jet at a distance of 3 or 4 centimeters from the nozzle, a slight increase in thickness can be detected where the impure gases meet the jet; but the effect is very slight compared with that produced when the gases are taken in at the origin of the jet.

The limited range of the action of cold is quite what might be expected. Near the nozzle the temperature of the jet is high, and there the drops have no repulsive action; but at a short distance from the nozzle the temperature is low enough to allow this repulsion to come into action, and the consequence is that any further cooling after the temperature is below a certain point produces little or no effect. It is only when the temperature is above this point that the cooling has any influence. The same explanation holds good for the limited range of the action of obstructions in front of the jet.

At a distance of a few centimeters from the nozzle new drops seem still to be forming, as the density of the condensation is slightly increased by increasing the supply of nuclei at that distance. The drops seem also occasionally to coalesce at a distance of 3 or 4 centimeters from the nozzle, as electricity slightly increases the density of the condensation even at that distance.

PART II.—COLOR CONNECTED WITH CLOUDY CONDENSATION.

In the following remarks it is not intended to discuss the many color phenomena which are known to be connected with cloudy condensation. Attention will be confined principally to some new phenomena, the experimental illustration of which has been developed in the present investigation.

Before describing these experiments it may be as well to refer to some changes which take place in the constitution of cloudy condensation, both while it is forming and after it has been developed, as it will be necessary for us to keep certain points in view while discussing the color phenomena. There are two points to which special reference is required. These are, first, the manner in which the appearance of the condensation is affected by the greater or less degree of super-saturation, that is, by the rate at which the condensation is made to take place; and, second, the changes which take place in the appearance of this cloudy condensation after the tendency for the vapor to deposit has stopped.

These two points may be best discussed by taking the second first. Suppose we blow some steam into the air inside a glass vessel and leave

it undisturbed. If we examine the cloudy condensation after a time we shall find that a considerable change has taken place in its appearance. The change is due to two causes. Part is due to the gradual descent of the particles, by which a clear space is formed in the upper part of the vessel. But it will also be observed that the clouding in the lower part is much thinner than it was at first. Probably part of this thinning is due to some of the particles having fallen to the bottom of the vessel, but this is not the principal cause of the change. The thinning is due mainly to a reduction in the number of particles in the air, by the smaller particles gradually becoming absorbed by the larger ones. This is caused by the vapor pressure at the surface of small particles being greater than at the surface of larger ones, with the result that the smaller particles evaporate in air of the same humidity in which the larger ones are condensing vapor.

We are now in a position to understand our first point, namely, why the degree of super-saturation by which the condensation is produced should have an effect on the appearance of the condensed vapor. For the study of this point the condensation produced by expansion is the most convenient, as it is more under our control than the condensation in steam jets. Suppose we take a glass flask connected with an air pump. If we wet the inside of the flask and then fill it with unfiltered air, the slightest expansion of the moist air by the pump will cause condensation to take place. But the density of the condensation which can be produced by any degree of expansion will depend on the rate at which the expansion is made. If the expansion be made very slowly, the clouding is very thin, but if it be made rapidly, it is very thick. If the expansion be done slowly, the amount of super-saturation is only slight, and only the largest dust particles come into action as active centers of condensation; and after a particle of dust has once become a nucleus, it has then, in virtue of its size, an advantage over the particles which have not begun to have vapor condensed on them. The result of this is that so long as the degree of super-saturation is very slight, these large particles relieve the tension, and if by any chance other dust particles become active any reduction in the rate of condensation allows the large particles, after they have relieved the tension, to rob the small ones of their burden of water, so that a slow rate of condensation always produces a small number of drops and a thin form of clouding.

But now suppose you cause the expansion to be made rapidly: the super-saturation then becomes much greater, as there is not time for the water molecules to select a resting place, and the small number of large dust particles can not relieve the tension, and the result is a much greater number of nuclei are forced into action. And all these nuclei continue to grow so long as the super-saturation is kept up, but the larger ones grow most. After the tendency to condense has begun to diminish, those particles which have accumulated least are the first to feel the change and cease to grow, while the larger ones are still accumu-

lating. But after the tendency to condensation has ceased altogether the changes in the clouded air are not at an end. The smaller drops begin to lose their accumulated moisture, while the larger ones are still growing—growing at the expense of the gradually diminishing smaller ones. This process goes on till most of the small ones have lost all their burden of water, which has been absorbed by the overgrown larger ones: and in the end a comparatively small number of drops have absorbed the moisture which was previously distributed over a vast number of particles. The larger particles have, so to speak, eaten up the smaller ones. How like the above looks to a page in the "struggle for existence" in the animal or vegetable world!

Color phenomena in steam jets.—Steam escaping into the atmosphere has been observed on a few occasions to have the power of absorbing certain of the rays of light, and causing the sun, when seen through it, to look "blue" or "green." Principal Forbes observed colors in the steam escaping from a safety valve. Mr. Lockyer* states that, when on Windermere, he saw the sun of a vivid green, through the steam of a little paddle boat. I believe a few others have seen this phenomenon under similar conditions, but so far as I am aware no one has followed out the suggestion and investigated the manner in which the color is produced.

Mr. Bidwell, in his experiments on the electrification of steam jets, studied the action of the jet on light by casting the shadow of the jet on a white screen, using for illumination the lime light. He found that the shadow of the ordinary jet—that is, the light transmitted by the jet—was nearly colorless, but that when it was electrified the shadow became of a dark orange-brown color.

The color of the "green sun" seen through steam has been attributed to the absorption of both ends of the spectrum by the aqueous vapor. This explanation is obviously not the correct one, as it will be found that a moderate length of steam has no perceptible selective absorption. Through a length of even 1 meter of steam white objects are not colored, and we shall presently see that the coloring depends not on the vapor, but on some action of the small drops of water in the condensing steam.

For the purpose of studying the color phenomena of steam jets I have found it to be a great advantage to surround the jet by solid walls. When a jet condenses under ordinary conditions, the constitution of the jet rapidly changes in its passage away from the nozzle, owing to the air mixing with it; and it has been found that by inclosing the jet in a tube, after a certain amount of air has been mixed with the steam, that the conditions can be kept fairly constant for some length of time, and the color phenomena taking place can therefore be more easily studied under these conditions. The tube used for this purpose need

* *Nature*, June 6, 1878; vol. XVIII, p. 155.

not be of any special size. For a jet from a nozzle of 1 millimeter bore a tube of 7 or 8 centimeters diameter and about half a meter long does very well, but a smaller and shorter tube may be used. With the larger size of tube it may be necessary to check the current through it. This is best done by placing a piece of glass near the exit end of the tube, the opening between the glass and the end of the tube being regulated to the required amount by observation. When a small jet of steam is used with the large tube open at both ends too much air is drawn in and the effect is much the same as if no tube were used. The end of the tube has, therefore, to be closed to a certain extent, to produce the color phenomena. But when high-pressed steam is used, no check on the circulation through the tube is necessary. The steam nozzle should be placed outside the tube and a little to one side, so that the eye can be brought into a line with the axis of the tube and a clear field of view obtained while the jet plays into the open end of the tube. This is an experiment which well repays the trouble of making it. When the amount of steam, dust, and other conditions are properly proportioned, the colors seen are very beautiful. With ordinary condensation the color varies from a fine green to lovely blues of different depths. The pale blues equal any sky blue, while the deeper blues are finer than the dark blues seen in the sky, as they have none of the cold hardness of the dark sky blues, but have a peculiar softness and fullness of color.

Suppose now the tube is fitted up pointing to a clouded sky, or other source of light, and that the steam jet, under slight pressure, is blowing through it. If the exit end of the tube be open we shall see very little color, and what is seen is only near the origin of the jet. If now we partially close the end of the tube with the glass plate, to prevent the jet drawing in so much air, we shall find that color begins to appear, and that when the plate is properly adjusted the tube looks as if filled with a transparent colored gas. The first decided color to appear is generally green, though I think I have frequently seen a pale crimson before the green was visible. If circulation be checked still further, the color will change to blue of a greater or less depth, according to the conditions.

The above are the effects which may be looked for when the condensation of the jet is ordinary; but suppose it be now caused to change to the dense form, then the color seen through the tube also changes. If, when the jet is condensing in the ordinary way, and the transmitted light is green, we cause the condensation to change to dense, then the color also changes and becomes deep blue, or, if the ordinary condensation gave blue, the color changes, when the jet is dense, to a dark yellowish-brown. But between the blue and the yellow there is always an intermediate stage when all color disappears and the light is simply very much darkened. The most common effect of the change of the condensation from ordinary to dense is for the transmitted light to

change from blue to a yellowish color, and it does not matter how the change in the condensation is effected; the color always changes in the same way. We can therefore cause the color in the tube to change by electrifying the jet, by a supply of cold air, by a supply of the products of combustion, by increasing the pressure of the steam, and by placing an obstruction in front of the nozzle. When any of these, either separately or combined, comes into action, the change is always in the same direction, and if the color was blue it changes to yellow.

It may be as well to note here that the yellows produced by most dense forms of condensation are far from fine, and can not be compared with the blues. The yellows are not at all unlike the colors occasionally seen through smoke or in a thunder cloud. Though this is the case with the dense condensation produced by most of the causes, yet a very fine yellow is obtained when high-pressure steam is used.

It has been suggested that, because an electrified jet causes the light transmitted through it to be colored of a dark yellow-brown, and as the color seen in thunder clouds is similar, that, therefore, the lurid color of thunder clouds is due to the electrification. From what is stated above it will be seen that electricity is only one of a number of influences which can change the condensation of the steam jet and make the light transmitted through it of a yellow-brown color. Further, there is no evidence to show that electricity has any influence of this nature on the form of condensation taking place in clouds, and we are hardly entitled to expect it to have any such influence, as the conditions under which the steam condenses in a jet are very different from those under which condensation takes place in clouds; and we have seen that electricity has no effect in the nature of the condensation when it takes place in a mixture of hot moist air and cold air. There is still another fact which points to the same conclusion. If, in the steam jet, the proportion of dust, pressure, etc., are such as to give an earlier stage than the blue, suppose the transmitted light be green, then the electrification may not change it to yellow, but may only make it blue. At present it is, therefore, very doubtful whether the electricity in a thunder cloud has anything to do with its color.

Colors observed in cloudy condensation produced by expansion.—Though previous experiments had made me well acquainted with certain color phenomena, seen when cloudy condensation is produced by the expansion of moist air in a receiver, yet I had never observed any colors in the light transmitted directly through the clouded air, such as are seen in the jet of steam when inclosed in a tube. It seemed extremely probable that the reason for this would be, that when the condensation is produced by expansion the process is slow, and the particles will therefore be too few to produce any color effects. In a steam jet the expansion, cooling, and condensation, take place very rapidly, and for that reason the number of water particles formed is

very great. An experiment was, therefore, arranged in which the air could be very rapidly expanded, so as to produce a high degree of super-saturation, which it was hoped would cause a great number of dust nuclei to become active. To test this idea, all that was necessary was that the receiver used for holding the moist air should be much smaller than usual in comparison with the capacity of the pump, and that the light be transmitted through some length of air. The plan adopted was to use an air pump of ordinary dimensions, and for a receiver a metal tube closed with glass ends. The first apparatus prepared for this experiment was found to give satisfactory results, and the alterations since made have not been of any great advantage.

The apparatus consists of a brass tube 2·3 centimeters diameter and about half a meter long. It is provided with glass ends, fitted on air-tight, and is provided with a branch pipe at each end. One of these branch pipes is connected with an air-pump, and the other has a stop-cock fixed to it. This stop-cock is connected with a pipe for bringing to the tube the air to be experimented with. If the tube be mounted horizontally, the particles rapidly fall and the phenomena are visible only a short time. The tube is therefore best mounted vertically, and with a mirror placed at the lower end of the tube to reflect the sky or other source of light up through the tube to the eye of the observer.

The air-pump used is a single cylinder instrument of 3·17 centimeters diameter and 19·3 centimeters stroke, so that its capacity is about three-quarters that of the tube receiver. If we take the instrument outside the house and make one or two strokes of the pump to fill the receiver with air of the place, then close the stop-cock, and make a rapid stroke with the pump, little effect is produced on the light transmitted through the tube. But if we take the instrument into a room where gas has been burning, so that the air is full of dust particles, and repeat the experiment, very beautiful colors are seen on looking through the tube when the air is expanded. Or better still, if we collect the gases rising from a small flame and draw them into the tube, the result is a display of an exceedingly lovely series of colors, full, deep, and soft, in some respects reminding one of polarization colors. As in the steam jet, the blues are the finest, and the tube looks, at times, as if filled with a solution of Prussian blue. The colors produced in this way are more uniform and equal in all parts than those seen in the steam jet, unless when the jet is very carefully adjusted; the yellows are also much finer, and the colors are more varied than those seen in the steam jet.

There is however one most disappointing thing connected with these colors produced by expansion: they are very fleeting. Their full beauty lasts but a second or two and they soon fade away, the color growing dimmer and feebler every moment. This is owing to the differentiation which takes place in the particles forming the cloudy condensation. As has been already explained, the small drops rapidly diminish in size while the large ones increase, and as in these experiments the drops

are very close to each other these changes take place the more rapidly. These changes are also taking place in the steam jet, but owing to the constant supply of new drops the older ones are swept away before the change is observed. The following experiment will however show that these changes are taking place in the steam jet also. If, while the jet is condensing and the transmitted light is yellow, we imprison some of the jet by closing both ends of the tube, we shall find in an extremely short time that the color will change to blue, after which it will fade, as the drops increase still further in size, and fall. In this experiment we have a proof of the statement that when the jet is electrified the drops are smaller than when not electrified, and not larger, as has been supposed. As this experiment shows, if we begin with drops transmitting yellow light, as the drops diminish in numbers and increase in size the transmitted light changes to blue.

The conditions of the experiments for producing color by cloudy condensation, produced by expansion, have been varied in a number of ways. After the air has been cooled by the expansion, the layer of cloudy air in contact with the walls of the tube rapidly acquires heat from the metal, and the rise in temperature quickly evaporates the cloudy particles and causes a clear space all round next the walls, so limiting the color to the center of the tube. The receiver was therefore increased in diameter to get rid of the disturbing effects of the heating of the air on the walls of the tube, so as to have a larger mass of air beyond this influence; but no decided advantage has been obtained. It was afterwards found that the difficulty of studying these color effects in small tubes can be easily overcome by wetting the inside of the tube. With this precaution the air next the walls is kept saturated and the temperature of the wall is lowered by the heat given off to evaporate the water, with the result that the color is the same all over the field and close up to the walls.

Large tubes might be used for showing these color phenomena to an audience, a parallel beam of light being sent through them, which would become colored when the dusty air in them was expanded. One large tube tried has a diameter of 7 centimeters and is 50 centimeters long. With a receiver of that capacity it would be hopeless to attempt to produce any color effects with an ordinary air-pump alone; a vacuum receiver has, therefore, been added to the apparatus. This receiver is made of metal; it is 15 centimeters diameter and 60 centimeters long, with round ends. There are two tubes attached to it, one for connecting it with the air-pump, and the other is provided with a stop-cock, to which a tube is attached, by which it is connected with the experimental receiver. The stop-cock is closed, and the pump worked till most of the air is taken out of the receiver; and when it is desired to expand the air in the experimental tube the stop-cock is opened, when a violent rush of air takes place, and the pressure is rapidly lowered in the experimental receiver and a dense color-producing form of clouding is obtained.

The conditions causing the different colors.—For studying the conditions which give rise to the different colors seen in these tubes, the air pump and the small tube will be found to be the most suitable. Supposing these to be fitted up, the following will show how the colors change with the conditions:

First, the effect of the degree of saturation of the air. If the air be dry the colors are not good, and some degree of expansion requires to be made before any effect whatever is produced on the air; and when the colors do appear, it is only in the center of the tube that they are seen, the space all round next the walls being free from condensed particles. As the humidity is increased, this unclouded space near the sides of the tube gradually diminishes. The colors are therefore best studied when the air is saturated and the inside of the tube wet. When this is done the colors extend to the wall and completely fill the tube.

Second, the effect of the number of dust particles in the air. If we use the ordinary outside air, the colors are very faint or invisible. Suppose some slight color is visible, then it will be found that a very slight expansion, say one fifth of a stroke of the pump, will give a pale blue, and if the expansion be increased the color will change. If now we use air from a room where gas is burning, and fill the tube with it, we shall now, on expansion, get a much deeper blue, and it will be observed that a greater expansion must now be made to get the best blue, and before the color begins to change. If we alter the conditions still further, and fill the tube with air in which is mixed a good deal of the products of combustion, we shall find that the condensation is now so dense that we can scarcely see through the tube; but it will be noticed that the color is a very deep blue, and that a full stroke of the pump was necessary to produce this deep blue, but in this case no change of color was produced with that large degree of expansion.

These experiments show that, with few dust particles, a slight expansion will produce the best blue, and that as the number of particles increases, the amount of expansion necessary to produce the best blue also requires to be increased, the depth of color increasing with the increase in the number of dust particles. The explanation of the differences here is very simple. With few particles a very slight expansion will deposit enough moisture to make the small number of drops of the size sufficient to give the best blue color; but, as the number of particles is increased, more moisture must be deposited before the increased number of drops are made large enough to give a full blue; hence, with a larger number of particles a greater expansion is necessary to produce this effect.

Third, the effect of the size of the condensed particles. As has been stated, a slight expansion produces a blue color if the number of particles be small, and if the expansion be increased after the blue is produced, the color changes; and we shall now describe the successive colors which appear as the degree of expansion is increased, that is,

as the size of the water particles is increased. When the expansion begins, blue is the first distinct color to appear, but very pale yellow and slightly reddish colors have been noticed before the expansion was sufficient to produce the blue. These reddish colors can be seen very distinctly when we use an excessively great number of particles, and they are best seen with gaslight. These reddish colors imperceptibly change into blue as the expansion is increased, and the blue in turn changes by minute degrees into green with further expansion, and the green in turn changes to yellow; then a brownish color appears, which changes to a somewhat mixed purple; then the blue returns again, to be followed by green and yellow, as the expansion is still further increased. It is not easy to get this sequence of colors carried so far. Sometimes one stroke of the pump only carries the color on to yellow; sometimes it may go to the second blue or green, but less frequently to the second yellow. The final color depends on the number of particles present. It is necessary to have a good many drops, so that the color may be distinct, and yet not too many or the expansion may not be sufficient to grow the particles large enough to give the second series of colors. It is found that a high expansion, produced by two or more strokes of the pump, does not give satisfactory results.

We have seen that by increasing the number of dust particles the depth of color was increased; it therefore seemed possible that these color phenomena might be made visible in even a short column of air, and that they might be shown by means of ordinary glass flasks. The following experiment was, therefore, arranged: A flask, about 18 centimeters diameter, was fitted with an India-rubber stopper, through which passed two tubes. One tube was connected with a metal vacuum receiver already described, the other had a stop-cock attached to it. The stop-cock was connected with a long metal pipe which led to a wide tube placed over a small flame. Air charged with the products of combustion was drawn into the flask through this pipe; when sufficient impure air was drawn into the flask, the stop-cock was closed; when the air in the flask was now suddenly expanded, it looked as if it had been filled with a transparent blue gas. The color, when held against a white cloud, was almost exactly the same as that of the blue sky. The color in the flask faded rapidly, as in the experiments with the tube. The particles being very closely packed in most of these experiments the subsequent change is all the more rapid.

Effect of temperature.—To observe the effect of temperature on these color phenomena, another tube was prepared, with glass ends, and jacketed, so that the air in it might be heated or cooled to any desired temperature. The result was very much what might have been expected; at the different temperatures all the colors made their appearance in the usual order, but there was a considerable difference in the amount of expansion required to produce a given color with change of temperature.

At a high temperature each of the colors appeared with a less expansion than when the temperature was low. In making these tests the number of dust particles in the air must be kept as constant as possible. For this purpose windows and doors should be kept closed for sometime before beginning, and the experiments should be repeated without change of conditions. When the air was cooled to about 35°, it took two strokes of the pump to develop a full blue, and three strokes made it only green. At a temperature little over 50°, two strokes made it green, while if the air was heated to about 80°, two strokes sent it past blue and green and on to yellow, and less than one stroke made it full blue. The differences are due to more vapor being present and being condensed, with the same amount of expansion, when the air is hot than when it is cold. It should be stated that in all cases the air was saturated, the inside of the tube being wet.

The tube was also cooled down to 6° F., but no difference was observed in the nature of the phenomena. The particles at that temperature seemed to be still in the liquid form.

Light transmitted.—The light transmitted directly through the cloudy condensation has been examined by means of a small spectroscope. One of the tubes was mounted vertically, and a mirror placed at the lower end; the spectroscope was temporarily mounted over the upper end of the tube; a small mirror was placed between the spectroscope and the glass end of the tube. This small mirror covered half the field of the spectroscope, and reflected light from the same source as that reflected by the mirror at the lower end of the tube, so that one-half of the field gave the spectrum of the light, and the other half the light after passing through the clouded condensation. The conditions in the experiment are too fleeting for satisfactory observation. The only thing noticed was a darkening of the whole spectrum, with a greater absorption at certain points than at others. When the light was blue, in addition to the general reduction in brightness, the red end was more reduced than any other part, and there was also a very marked shortening of the spectrum at this end. When the color was yellow the reverse was the case. The blue was almost entirely cut out, while the yellow was far the brightest part of the spectrum.

An examination has also been made of the diffraction colors as seen in the halos surrounding bright lights. The most convenient way tried of observing these colors was to use an ordinary glass flask of 18 centimeter diameter, connected with the metal vacuum receiver, as already described. For the source of light, gas may be used, but a better result is obtained with the light of the sky. In order to observe these colors easily the window should be closed, all but a narrow vertical strip; and it improves matters to have all surfaces on each side of the opening painted black. When the air in the flask is expanded.

the vertical bands of diffraction colors are distinctly seen on each side of the bright light. If now we keep the amount of dust in the air constant during the experiments, we shall find that, on opening the stop-cock to the vacuum receiver very slowly, we will get the usual cloudy condensation, and that the diffraction colors will be quite distinct. But if we repeat the experiment and this time open the stop-cock very suddenly, so as to cause a rapid expansion, the colors will be found to be very much improved, being far more brilliant. This is due partly to the greater number of particles engaged in producing the effect, but chiefly to the much more equal size of the particles when they are suddenly developed than when slowly grown.

It is found that we must not have too many particles present, or the diffraction colors will not be good; their size does not seem to be great enough to produce the phenomena. If, for instance, in place of using the air of the room, we take into the flask air coming from a small flame, the color phenomena in the flask all change: when there were few particles the light transmitted directly through them has so little color it is not noticed, while the diffraction colors are fine; but with many particles the direct light becomes colored, while the diffraction colors are softened and have lost much of their brilliancy. When the particles are sufficiently numerous to cause the directly transmitted light to be of a thin blue, the diffraction color next the blue light is nearly the complementary yellow, and this yellow light extends to near the limits of the flask. If more particles be added, the color of the transmitted light becomes deeper blue, but it is difficult now to say what the diffraction colors are. The convection currents in the flask now make themselves visible; the air on each side of the blue direct light is suffused with a variety of colors, not now in regular vertical bands, but irregularly distributed and in movement through the flask.

Cause of the color.—These experiments show that the color produced by the small drops of water depends on the size of the drops, and the depth of color in their number. But it is not so easy to follow the manner in which the drops produce the color. If we take the simplest case, we can easily see how part at least of the color is produced. In the steam jet condensing dense, and coloring the transmitted light yellow, part of the effect is no doubt due to some of the particles in that form of condensation being so small that they reflect and scatter the shorter waves of light, while they allow the longer ones to pass through. The color in this case is partly caused in the same way as the yellow produced by small particles suspended in liquids, as in Bruck's experiment with mastic, or as when silver chloride is formed from a solution of the nitrate. The light reflected by the liquids in these experiments is of a bluish tint, complementary to the yellow light transmitted by them, and this blue light is polarized. It has been found that when the steam jet is of a good yellow by transmitted light, it reflects a good deal of a

bluish light; and, further, this blue light is polarized in the same way as the light from the small particles in the experiments with liquids.

While this explanation helps us so far to understand the manner in which the yellow light is produced in steam jets, yet it fails to explain the succession of colors seen in the expansion experiments, where blue first appears, then green and yellow; and when the expansion is still further increased, the blue again returns to give place to a second green and yellow. The most probable explanation of these color phenomena is that they are produced in the same way as the colors in plates, somewhat after the manner Newton thought the color of the sky was produced. The order of succession of the colors in thin plates is the same as in these condensation phenomena. As no white follows the first blue, it seems probable that the first spectrum, or order of colors, is not observed; that the two generally seen are the second and third.

Some experiments were made with a glass tube receiver, in place of the metal one, to see if there were any colored light reflected in these expansion experiments of the same kind as is seen under certain conditions in a steam jet; but no such colors have been observed. It is possible they may be present; but, owing to the great amount of white light reflected by the larger particles, any colored reflected light that may be present is masked.

Green sun.—On a few occasions the sun has been observed to be of a decidedly greenish color, while on other occasions it has appeared blue. The experiments which have been described in this paper seem to offer an explanation of this phenomenon. For a number of days in the beginning of September, 1883, the sun was seen of a decidedly blue or green color in India, Trinidad, and other places. Most of the observers who have written on the subject have linked this phenomenon with the eruption of Krakatao, which took place just before the days on which the green or blue sun was seen. From the light thrown on the subject by these experiments, we see that an eruption, such as that of Krakatao, would throw into the atmosphere a supply of the very materials necessary for producing a green sun by means of small drops of water, as it would send into the atmosphere an immense quantity of aqueous vapor and an enormous amount of fine dust—a combination the most favorable possible for producing a great number of minute drops of water.

Prof. C. Michie Smith observed the green sun in India, and he says:

"The main features of the spectrum taken on the sun when green were:

"1. A very strong general absorption in the red end.

"2. A great development of the rain-bands and of all other lines that are ascribed to the presence of water vapor in the atmosphere."*

It is evident, therefore, that one of the materials necessary for producing this peculiar absorption by means of water drops was present in an unusual amount in the atmosphere at the time; and it also

* *Nature*, Aug. 7, 1884; vol. XXX, p. 347.

appears that a fine form of condensation had taken place, as Mr. W. R. Manley states* that there was at the time a sort of haze all over the sky, and from the letters of different observers this haze seems always to have accompanied the great sun.

One almost wonders that a blue or green sun is not oftener seen, as there are often present all the materials necessary for producing these colors in the atmosphere. On a few occasions I have observed the sun to be of a silvery whiteness, when the vapor in the upper air was beginning to condense, and the sky was covered with a thin filmy cloud. It is however possible that this slightly bluish tint may have been due to the sun being seen more in its natural color than usual; that is, made much less yellow by our atmosphere than it generally is. There seems to be something preventing the dust and the vapor in our atmosphere acting under ordinary conditions in such a way as to color the sun blue or green. Perhaps it may be the tendency the particles have to differentiation. This tendency, we have seen from the experiments, rapidly destroys all color effects, and from this we might suppose it would be impossible that the colors if produced by water drops could remain in nature visible for so long a time as they did. But it must be remembered that the particles in the experimental vessels are extremely close together, and the vapor exchanges can therefore take place quickly. If however the drops were widely separated, the exchanges would take place slowly. For instance, if the drops in 1 centimeter were separated so as to form a column 1 mile long, with a section of 1 square centimeter, we should have the same amount of color in 17 miles that we had in the 17 centimeters of air in the flask, and the particles would be so far apart that differentiation would then take place extremely slowly. But further, if the supply of dust and vapor were constantly kept up by the volcano, the color phenomena would continue for the same reason that they continue in a steam jet, namely, by the drops being constantly renewed.

A new instrument for testing the amount of dust in the air.—As this investigation progressed it became evident that these color phenomena placed in our hands an easy and simple way of estimating, in a rough way, the number of dust particles in the atmosphere of our rooms, which might be useful for sanitary purposes. An instrument was therefore constructed to see how far the idea could be practically carried out. This new instrument we intend to call a *Koniscope*. In its present form this instrument consists of an air-pump and a metal tube with glass ends, which we shall call the test-tube. The capacity of the pump should be from half to three-quarters the capacity of the test-tube. Near one end of the test-tube is a passage by which it communicates with the air-pump, and near the other end is attached a stop-cock for admitting the air to be tested. The test-tube and air-pump may be attached parallel to each other, and held vertically when

* *Nature*, Oct. 11, 1883; vol. XXVIII, p. 576.

observing. If this arrangement be adopted, a mirror must be attached to the lower end of the tube. In practice it is found to be more convenient to omit the mirror, and observe with the tube in any position, simply directing it to any suitable light. When this arrangement is used, the pump, for convenience of working, should be attached at right angles to the test-tube. It is found that any want of uniformity in the color of the field produced by the air heated on the sides of the tube can be greatly obviated by lining the inside of the tube with a non-conducting substance and keeping it wet. Blotting-paper is found to do very well, as it holds plenty of water for saturating the air and is a fair non-conductor. When the inside of the tube is lined with it, the field of color is fairly uniform, owing to the cooling of the sides by the evaporation when the air enters and when expansion is made.

For illumination no doubt day-light is the best when it can be obtained, as gas-light is so deficient in blue rays that color is not well observed. For convenience of observation, it is found to be best to close the far end of the tube with ground glass, and when working with artificial light ground glass must be used.

I have made a few tests with an instrument of this kind, and find it very easily worked, and, for my practical purposes, it is sufficiently accurate. It can not of course compare with the dust counter for accuracy; but, on the other hand, it is a much less expensive instrument, and tests can be made far more easily with it, and little special knowledge is required. If we wish to get actual figures for the amounts of dust indicated by this instrument, then it must be graduated by a dust counter. The indications at best, however, will only be very rough approximations to the numbers. There are three ways in which we might graduate this instrument. We might, for instance, make one full stroke of the pump and note the color which appeared. This color would indicate the number of particles. For instance, if there are few particles, one stroke will make the light first blue, then green, then yellow, and then a second blue and green, and finishing with yellow. But if there are a good many particles present, the same amount of expansion will only make the first series of colors to appear; and if a great many particles are present, the one stroke will not give the whole of the first series of colors, but may stop at the blue. If the temperature of the air were always the same this method might be adopted; but, as we have seen, an allowance would be required to be made for temperature, as, with a high temperature, the same degree of expansion carries the color further up the series.

Another method of graduating might be to note the amount of expansion necessary to give any particular color, say, to give the best blue. With few particles a slight expansion gives the blue, while with many particles a much greater expansion is necessary. But here again the effect of temperature comes in. Temperature observations would there-

fore require to be taken, and a correction made which it might be difficult to carry out in practice.

At present the best plan of graduating seems to be to note the depth of the blue produced, regardless of the amount of expansion required to give it, and use only this quantity as an index. With few particles the color is pale, and as the particles increase in number the color increases in depth. Perhaps some addition might be made to the instrument for estimating more accurately the depth of color than can be done mentally. This might be done either by means of colored glasses of different depths for comparison, or in some other way.

A few comparative observations have been made with the *koniscope* and the dust-counter in the impure air of a room. While the number of particles was counted by means of the dust-counter, the depth of blue given by the *koniscope* was noted. A metal tube was fitted up vertically in the room in such a way that it could be raised to any desired height into the impure air near the ceiling, so that supplies of air of different degrees of impurity might be obtained. To produce the impurity the gas was lit and kept burning during the experiments. The air was drawn down through the pipe by means of the air pump of the *koniscope*, and it passed through the measuring apparatus of the dust-counter on its way to the *koniscope*. The indications of the two instruments were taken, and are entered in the following table:

Dust-counter particles per cubic centimeter.	Koniscope, depth of color.
50,000	Color just visible.
80,000	Very pale blue.
500,000	Pale blue.
1,500,000	Fine blue.
2,500,000	Deep blue.
4,000,000	Very deep blue.

It is probable that the higher numbers are too low, as the measure of the dust-counter has a capacity of only 10 cubic millimeters. With so small a measure it is probable that a good many of the particles are lost. When making a sanitary inspection, the air outside, or wherever the supply was drawn from, would be tested first, and the depth of color which it gave would be noted. Any increase from that depth would indicate that the air was being polluted, and the amount of increase in the depth of color would indicate the amount of increase of pollution Slight color can be traced, though the number of particles be less than 80,000 per cubic centimeter, but the color is not very decided, the condensation producing principally a darkening effect. It should be noted that the above table refers to a koniscope with a test tube 50 centimeters long. An instrument with a tube 1 meter long would be doubly sensitive and would show color with fewer particles.

It is thought that the *koniscope* will be useful for sanitary inspectors for investigating questions of ventilation in rooms lighted with gas and for other purposes. As an illustration of what this instrument can tell us, the following experiment may be given. It shows us how we can trace by means of it the pollution taking place in our rooms by open flames. The room in which the tests were made is $24 \times 17 \times 13$ feet. The object of the tests was to see if the *koniscope* could tell us anything definite about the degree of pollution at the different parts of the room, and also about the rate at which it was increasing. For this purpose a small tube was arranged so that one end of it could be raised to the ceiling or into the air of any part of the room from which it was desired to take the air; the other end of the tube was connected with the *koniscope*.

The first thing to be done was to examine the air of the room before lighting the gas and beginning the tests. On doing this the air at the level of the observer gave a very faint color, scarcely perceptible; air drawn from within 3 inches of the ceiling gave equally little color, and the air inside the room gave the same color as the air outside. The upper end of the tube connected with the *koniscope* was then raised to within 3 inches of the ceiling, near one end of the room, and the *koniscope* left attached to the lower end. Three jets of gas were now lit in the center of the room and observations at once begun with the *koniscope*. Within thirty-five seconds of striking the match to light the gas the products of combustion had extended to the end of the room; this was indicated by the color in the *koniscope* suddenly becoming of a deep blue. In four minutes the deep blue-producing air was got at a distance of 2 feet from the ceiling. In ten minutes there was strong evidence of the pollution all through the room. It was strongly indicated near the windows, owing to the down current of cold air on the glass. This impure down current could be traced to the floor, and onwards to the fire-place; while a pure current could be traced from the floor to the fire-place. In thirty minutes the impurity at 9 feet from the floor was very great, the color being a deep blue.

The wide range of the indications of the *koniscope*, from pure white to nearly black blue, makes the estimates of the impurity very easily taken with it; and, as there are few parts to get out of order, it is hoped it may come into general use for sanitary work.

The few experiments I have made with this instrument have clearly pointed out that a window is not an unalloyed blessing as regards the purity of the air in our rooms, however much we may have been in the habit of thinking otherwise. In all cases it has been found that in rooms where gas is burning the air near the window is very impure. This impure down current of air near the window has been traced by the *koniscope* in all rooms tested. The impurity is caused by the cold air on the window sinking and drawing down the impure air near the ceiling, and this impure air is mixed with the lower air which we are

breathing. This effect is, of course, greatest when the windows are unprotected by blinds, shutters, or curtains. It is evident that, though a window may supply pure air when it is open, it yet does much harm when closed by bringing down the impure air, which, if undisturbed, would have a less injurious effect.

It is to be regretted that this investigation does not promise to yield much of practical value; nevertheless, as we cultivate not only fruits but flowers, so, for the same reason that we cultivate the latter, it is thought that these experiments will repay the attention of physicists. The colors produced by such simple materials as a little dust and a little vapor are as beautiful as anything seen in nature, and well repay the trouble of re-producing them.

ON CHEMICAL ENERGY.*

By Dr. W. Ostwald,
Of the University of Leipzig.

During the scientific development of chemistry the hypotheses which have served as a primary foundation have always been borrowed from a prominent sister science. At the time of the most rapid development of mechanics as founded by Galileo and advanced by his pupils and successors, chemistry was mechanical; the solvent action of acids upon metals was explained by assuming that the former possessed points and edges by means of which they disintegrated the latter; bodies which combine were supposed to have hooks by means of which they attached themselves to each other. When Newton based his theory of astronomical movements upon the assumption of a force acting inversely as the square of the distance, chemistry shortly appropriated this idea, and traced all processes to the attraction and repulsion of particles. It is therefore not surprising that the phenomena of the Voltaic pile (which later proved to be so intimately connected with chemical changes) were at once utilized to serve as a foundation for a theory of chemical processes. These theories, especially that of Berzelius, have prevailed a long time, but finally have proved themselves just as insufficient to represent chemical phenomena as the mechanical and the attraction theory.

Thus the theory of chemical combinations is to-day a strange and contradictory conglomerate of the fossil constituents of the earlier theories. The rudiments of the theory of attractions still play the most important role, while there is also considerable discussion about positive and negative elements, i. e., the residues of the electro-chemical theory, and in most recent times we see the long-forgotten mechanical conception again stepping to the front in stereo-chemistry and being accepted by many as a new step in the progress of science.

In such times it is of great value, on the one hand, to recall the historical development and the evanescence of theories; on the other hand to find in the older theories that which is useful and correct, so as to obtain sound building material for a new theory.

* Read before the World's Congress of Chemists, August 26, 1893. (From *Journal of the American Chemical Society*, August, 1893, vol. xv, pp. 421–430.)

Especially are we forced to conclude, from the fate of past theories, that chemical phenomena must be explained by their own inter-relations; that is, must be logically arranged. The use of analogies from other fields of natural science has indeed often led to suppositions which for the moment seemed satisfactory; on trial, however, such analogies have always proved themselves more a drawback than a help, since they hindered the unbiased comprehension of facts, and they could not (or will not in the future) be cast aside without a great struggle and considerable sacrifice of time and labor.

It is scarcely needful at present to prove that the several provinces of quantitative science possess in a single conception both the principle which distinguishes them and that common principle which unites them, namely, the conception of energy. Mechanical energy is distinct from thermal. Similarly, chemical energy is distinct from electrical; and in each province progress can only be made by studying the various properties which the form of energy under examination possesses.

At the same time, however, the laws which determine the correlation and conservation of energy constitute the only bond which unites the various fields. If heat could not be changed into mechanical energy and chemical into electrical, these provinces would stand distinct and isolated from each other; and neither thermo-dynamics nor electro-chemistry would be possible. This shows that progress in the scientific conception of chemical phenomena depends upon primarily determining the several properties of chemical energy as such, and then its relation to other forms of energy. This done, we will be able to cope in a scientific manner with each chemical process, no matter whether it leads to other chemical changes or causes the appearance or destruction of other forms of energy.

The knowledge of the laws of chemical energy is not only scientifically but also practically of the greatest interest. All energy, which is employed in accomplishing the various purposes of industry, is derived from chemical sources, the combustion of fuel. Besides, each step that we take, every word that we speak, in fact every thought formulated by our brain, leads to sources of chemical energy; animals and plants throughout their whole existence are based primarily upon chemical energy and its laws, and the ultimate problems of biology are in every respect chemical.

All forms of energy have this in common, that they may be resolved into two factors, both of which have definite properties. The one, which we call intensity, determines whether the energy may remain at rest or must undergo an exchange. Thus, for instance, the factor of intensity for heat is temperature, since we know that two bodies can be at rest with reference to their heat only when their temperatures are equal. The second factor we call capacity; it determines how much energy at a given intensity is present in the object under consideration. With heat, for instance, this is called heat capacity.

What now are the factors of chemical energy? If we had a measure for its factor of intensity, as the thermometer is a measure of the intensity of heat, we would be able to determine for each substance with reference to another whether it could react with the latter or not, just as the thermometer shows us whether or not heat can be transmitted from one body to another. Our answer is that this question has not been completely solved, but that from many phenomena we already possess a *chemometer*, as we might call the instrument—in analogy to the thermometer.

In order however to be able to explain the theory of the chemometer, the factors of chemical energy must first be more precisely determined. The factor of capacity is in this case most easily discovered. The chemical energy which is present under given circumstances is proportional to the weight or mass of the substances involved. Hence we sell and buy chemical energy according to weight. This becomes more clear from the following consideration: When we buy coal, we do not consider the carbon present, but rather the chemical energy, since in the use of the fuel we allow the carbon to escape quietly through the chimney as carbon dioxide, without making any effort to retain it; that however which we husband with the greatest care, is the chemical energy of the coal, obtained as heat. I have stated with due consideration that the factor of capacity of chemical energy is proportional to the mass; yet it is not mass, since this conception belongs solely to mechanics. It is therefore by no means more correct to say "atomic mass" instead of "atomic weight," since in this case the degree of chemical capacity is concerned which is proportional to both weight and mass, without being one or the other.

The term "degree of intensity" of chemical energy has something in common with the conception which has become familiar in the field of chemistry under the term of "chemical affinity," more to denote that field in which a more accurate knowledge was especially desirable than to combine by such a word sufficiently definite ideas. The word was there, just as the name of a future street stands on a signboard in the outskirts of a city, in a waste field; tents and barracks of the most curious kind have been erected from time to time only to be deserted again. Only in most recent times solid buildings and permanent settlements have found a place on this site, and soon a new section of the city will be created there, whose importance threatens to throw the older portion of the city in the shade.

J. Willard Gibbs called the degree of intensity of chemical energy the chemical potential; analogous to the degree of intensity of electrical energy, which is called the electrical potential. So, to avoid the vagueness of the term *affinity*, we will make use of the term chemical potential, or in brief, potential.

Now, it follows from the definition of the degree of intensity, that two substances with like potential can not act on each other: and, con-

versely, that when two substances act on each other their potential must be different.

That general law which can be regarded as expressive of the Second Theorem holds also for the chemical potential, namely: Two potentials which individually are equal to a third are equal to each other. This proposition seems quite self-evident, and therefore equally meaningless. Yet we can draw from it conclusions that are very far reaching. It says that two bodies or groups of bodies which are in equilibrium with each other, can mutually replace each other at pleasure towards a third system in every reaction in which this third system (towards which equilibrium has been established) can react. Thus, for example, every soluble body can be replaced by its saturated solution, every liquor by its saturated vapor, every solid body at its fusing point by the melted body without causing any alteration in the equilibrium depending upon the former. Among other things this shows that while the heat of solution, fusion, and evaporation, change the evolution of heat during a chemical process, they do not thus affect the equilibrium. The thermal theory of affinity, which is even to-day championed by Berthelot and others, is by this circumstance proved to be quite untenable.

It is natural in the case of such a far-reaching proposition to require proofs. This proof is found in the fact that it is impossible to create a *perpetuum mobile.* To have a *perpetuum mobile* it is not necessary to create energy from nothing, but only to transform potential energy into kinetic. If it were for instance possible to transform the constant heat which is present in enormous amounts in the ocean into work which then could change back into heat, we would require no more coal to propel our steamships, since all the work which we required for their propulsion would be transformed into heat by friction and could return to the ocean in unchanged amounts. Such a *perpetuum mobile* will be instantly possible when two substances which individually are in equilibrium with a third are not in equilibrium with each other. If we assume that a substance A, when in contact with a large body B (the ocean), assumes a temperature which is different from that imparted to a body B, simultaneously in contact and equilibrium with the ocean, we would cause a transmission of heat between A and B which would be capable of driving a machine. This proof is equally true for every other form of equilibrium and for every form of energy, and thus we also prove our chemical proposition.

When we have thus recognized the conditions under which energy is in equilibrium or at rest, we can directly reason that energy can not be at rest when its potentials are different. A process must then take place by means of which they become equal. This is the most common phenomenon with which we are acquainted; everything which takes place is based, in the last instance, upon an equalization of energies of different potentials.

Since however energy, as is a fact, has a never-ceasing tendency to

equalize itself, the question arises why it has not done so long ago during the many thousand years which our system of worlds has existed. We continually see differences of potential existing in nature—compressed air, galvanic elements; all these contain stores of energy which are ever ready to act and must therefore be unequal. Likewise the fossil fuels and the sulphides of the metals are able in conjunction with the oxygen of the air to bring forth large amounts of energy during their inter-action, and can not, therefore, be in equilibrium. Aside from the tendency for equalization, which is peculiar to energy, other forces are therefore active in nature which hinder or detain this, and an accurate understanding of these natural phenomena can only be attained when these opposing and detaining causes are known.

For mechanical and electrical energy such hindrances can be easily created. A spring may be kept wound by a weight; two electrically charged bodies, which tend to approach each other, can be kept from attaining their equilibrium by the dielectric resistance of an interposed medium. All these hindrances however have but this explanation, that the differences of energy present are compensated by the use of other energies, so that their equalization is prevented; at the same time, we can prove that, according to the method employed, large quantities of one form of energy of any magnitude can be compensated by equally small quantities of another form of energy, for by means of a small switch, enormous currents of electricity can be interrupted and closed at will.

In the case of chemical energy we are however very often unable to prove such compensations by the application of other energies. When a piece of wood is exposed to the air, it would be in accordance with the general tendency to equalize the energy present, if combustion took place and the wood combined with the oxygen of the air. The same would apply to organized bodies. Our body consists of combustible substances; and, in accordance with the chemical affinities present, it should combine with the oxygen of the air and burn without cessation. Why is it not consumed?

If we should attempt to answer this question we should soon become entangled in inexplicable contradictions. We can not ask: "Why is our body not consumed?" since it does actually burn. It continually takes up oxygen and gives off carbon dioxide. The same answer applies to other chemical phenomena. A stick of sulphur exposed to the air seems unchanged, but it is only apparently so. In reality it is oxidized; slowly however, and so slowly in fact, that we would not notice it in weeks or months. If the process were however continued for years or decades of years the oxidation could be measured. The rapidity of reaction is clearly proportioned to the surface. If we take finely powdered sulphur, flower or milk of sulphur, whose total surface is much greater, we can prove the formation of sulphuric acid in hours and days.

What has here been stated for a few cases is a general truth. In every case where different substances which could act upon one another are in contact without having, practically speaking, any apparent action upon each other, we can bring the requirements of the teachings of energy into unison with the actual conditions by actually ascribing to these substances an action which is, however, so slow that it lies beyond the possibilities of measurement.

We have here the means of entering upon one of the most important and mysterious problems, namely, the search after the chemical activity of organized bodies, for, as all the activity of organisms depends upon changes in their chemical energy, all knowledge in this case depends upon a correct elucidation of the character of the chemical changes. If we can understand how the chemical processes of combustion, to which all physiological sources of energy finally lead, can be so regulated that they are able at any moment to adapt themselves to the ever-changing requirements of the organism, we have taken a step in every respect most important in the knowledge of life.

Let us take, for instance, a mixture of oxygen and hydrogen. Under ordinary circumstances we can preserve this mixture for a long time without the formation of a measurable amount of water. If however we place a piece of platinum sponge into it the formation of water immediately begins, and it is as suddenly terminated when we remove the sponge. The platinum sponge has moreover undergone no change and is able to exert this action for an unbounded space of time.

At first it seems as if we had here the first proposition of our later natural science, to rudely dispute "*causa arguat effectum*," since we have here a cause which can bring forth extended and large effects at pleasure without becoming exhausted. If we ask however what this proposition means by cause and effect we find it to be degrees of energy. No energy of any kind can be created without the consumption of an equal amount of energy, and no difference in the potential of energies can be called forth without the simultaneous disappearance of equivalent differences in the potential of other energies. The truth of these propositions is not cast in doubt by the experiment with the mixture of oxygen and hydrogen, since the heat of combustion remains the same both when combination is effected by an electric spark and when it is brought about at the ordinary temperature by means of platinum sponge. While therefore the law of cause, clothed in the form of a principle of energy, regulates the final result of the action in an unchangeable manner, the time during which this action takes place remains absolutely independent of this principle, and we have side by side with the absolute necessity of this law of cause, the freedom with reference to the time during which it exerts its influence. Therefore we see that all possible phenomena which, originating from the same substances, reach the same products, arrive at these with a very different rapidity. The object to be arrived at is unchangeable; whether

it is however to be accomplished in a second or in several thousand years is a circumstance over which we have full control.

The name "catalytic bodies" has been given to substances which cause chemical reactions without experiencing any change themselves. We will now change this definition so as to read thus: Catalytic substances are those which modify the rapidity of a definite chemical reaction without changing their own content of energy. To place a catalytic substance into the reacting bodies and to remove it requires theoretically no work. This proves that within the strict province of the law of energy there still remains room for the greatest variation in the temporal extent of the phenomena.

This peculiar circumstance has its foundation in the fact that in the expression of most degrees of energy time is not mentioned, and that therefore the equation of energy does not determine the extent of time involved in the phenomena.

One exception is made in the case of kinetic energy, which depends upon the rapidity. What has been stated above does not, therefore, apply to this form of energy. Upon what the action of catalytic substances depends is still a mystery, the solution of which is the more difficult, since it can only be explained by means of new principles, which are beyond the law of energy. At present we must be satisfied with the knowledge that it is a fact and must seek to become acquainted with the laws involved. A beginning has already been made; from a large number of various investigations it has been found that many chemical reactions, which usually take place very slowly, are hastened by the presence of free acids; or, to speak in the language of the modern theories, by the presence of free hydrogen-ions, and that this action is proportional to the concentration of the latter. The greatest variety of phenomena have been examined in this respect, partly by me, partly by my pupils, and I have as yet found no case where this statement did not apply. Free hydrogen-ions are therefore without doubt exceedingly active catalysators of a general character.

At the same time numberless *specific* catalysators exist which act only upon certain phenomena. These are the ferments organized and unorganized. These also are unable to do more than to change the rapidity of certain reactions in one or the other respect, and all attempts to explain their action must be based upon this their sole property. The laws which they obey appear to be of an extremely complicated nature, especially with the more complex constituted ferments. This is probably due to the fact that they undergo a change themselves while influencing a certain chemical reaction.

I need not show in an extended manner that the wonderful action of living organisms can be traced to a regular impulse upon the chemical processes which take place among their constituents in accordance with general chemical laws, and that these again may be traced to the action of catalytic substances. If the rapidity of reaction in a muscle

is hastened which may be regulated from a central organ, this muscle will accomplish a corresponding amount of work. When however the supply of energy is exhausted, the influence of a catalystor can not force it to any further manifestations. The same is true for all other activities of organisms.

I can not assume to have made clear the mystery of life in the previous pages, but I believe that I have solved a more apparent problem, namely to show that the science which is seemingly abstract and foreign to actual life, and which has developed during the last years under the name physical chemistry, is a science of the highest real importance. If it will be possible for this science to throw light upon that most difficult of all the problems of nature, the mystery of life, how much easier will it be to explain by means of the new principles the by far much easier problems of technical chemistry which have not been solved so far. It is quite natural and self-implied, but we must nevertheless repeat again and again that "The more perfect the theoretical evolution of the sciences becomes, the greater will be the scope of their explanations and at the same time the greater their practical importance."

THE AMERICAN CHEMIST.*

By Prof. G. C. CALDWELL.

I have chosen for the subject of my address as retiring president of this society, one that seems appropriate to this occasion of the first gathering of a representation of American chemists on a fully organized basis as an American Chemical Society. My topic is the "American Chemist; his Past and Present;" and if I were but a prophet I would venture to add, his future. Even as a historian I can claim neither special gifts nor training, and what I may have to say must be regarded only as a contribution to the treatment of so large a subject.

The earlier records of the work of the American chemist are to be found only in periodicals of a general scientific character; for it is only within comparatively recent years, as we know, that he has been fortunate enough to have journals devoted exclusively to his own science. Before the establishment of these chemical journals, the *American Journal of Science and Arts*, better known as *Silliman's Journal*, contained almost the entire record of his work. Besides and before this were only Transactions of scientific societies, to which, however, he was but a meager contributor, with a few notable exceptions.

The oldest of these Transactions were those of the American Philosophical Society of Philadelphia: contemporaneous therewith was the *New York Medical Repository*. My history begins with what I can find in these periodicals or Transactions. Believing that the whole history can be presented in a more interesting manner if I divide the period over which it extends into distinct subperiods, I will give my account of it by decades after and inclusive of the year 1800. What little there is on record of the American chemist's work prior to that year may be included in one period and set forth in a few words.

Of that time, just at the close of the last century, Dr. Priestly was the most prominent figure in chemical science. Indeed, if it had not been for his coming to this country, and his persistent devotion to the doctrine of phlogiston, and the opponents whom he aroused, there would have been exceedingly little to note of chemical work of any

*An address delivered by the retiring president of the American Chemical Society at the sixth general meeting, Pittsburg, Pa., December 28, 1892.—From *Journal of the American Chemical Society*, December, 1892, vol. XIV, pp. 331–349.

kind. As far back before this as 1769 a paper was read before the American Philosophical Society, and published in the first volume of the Transactions, entitled "An analysis of the chalybeate waters of Bristol, in Pennsylvania," by one Dr. DeNormandie. This being, I think, the first chemical analysis made in this country, an account of it in the author's words will not be inappropriate. It runs as follows: Exp. (I) "A small portion of white oak bark infused in the waters induced an immediate change from transparency to a dark purple color, which it retained twenty-four hours without depositing any sediment. (II) Some of the same water after being made hot, or exposed for a few hours to the open air, in a great measure lost its irony taste, and received no other color than that of a common tincture from the white oak bark. (III) One drop of strong oil of vitriol in 2 ounces of the water produced no sensible alteration, and the water after standing some time continued transparent, without depositing any okerish or other sediment to the sides. (IV) Ol. Tart. pr. deliq. dropped in some of the same water induced a change of color, rendering it somewhat yellow, and in time precipitated to the bottom of the cup a fine gold-colored oker. (V) Sixteen ounces avoirdupois carefully evaporated to dryness in a china bowl in B. M. (*bain marie*, *i. e.*, sand bath) left one grain of a yellowish brown powder of the taste of tart. tartariz. (VI) Linen moistened with the scum floating on the top of the spring is tinged with a strong iron mold. (VII) This water in weight is exactly the same as rain water. From these experiments it is sufficiently evident that this water in its natural state contains a large portion of iron dissolved in pure water by means of an acid, which acid is extremely volatile and of the vitriolic kind."

In another paper the author goes on to describe nine other experiments of the same sort, from which he concludes that his first deduction is confirmed that the water contains considerable iron, that the acid must be either vitriolic or nitrous, that there is a small portion of neutral salts in these waters, that they contain sulphur, and that they are slightly alkaline. The author then discusses the medical properties of the water, comparing it with the German Spa.

Nothing else appears till 1793, when there is published an account of an earthy substance found near Niagara Falls, and vulgarly called "spray of the falls."

We turn from such crude work as this, even though probably the best possible at the time and place, to that of Priestly and his opponents, with a sense that we have hold of something of far greater importance, even if the main writer was all wrong in his theory. His first paper printed in this country appeared, I think, in 1796, in the same Transactions on "Experiments and observations relating to analysis of atmospheric air;" also, further experiments relating to "Generation of air from water," the conclusion from which is that water is convertible into phlogisticated air. From this year on to the end of the century he pub-

lished numerous short articles in this periodical and in the *New York Medical Repository.*

In December, 1799, he read a paper before the American Philosophical Society on "Change of place in different forms of air through several interposing substances," and, says Dr. Bolton, "recognizes distinctly for the first time the phenomenon of gaseous diffusion." In the volume of the New York Medical Repository for 1798–'99 he published eight letters to Dr. Mitchell defending the doctrine of phlogiston. In the same journal Dr. J. Woodhouse, professor of chemistry in the University of Pennsylvania, had many papers, from 1795 to 1800 and beyond,—opposing Dr. Priestley's phlogistic views. What meager showing this is, when we consider that on the other side of the ocean, we find in the *Annales de Chimie*, the first volume of which appeared in 1789, such names ot French chemists as Fourcroy, Lavoisier, Berthollet, Chaptal, Sennebier, Pelletier, Seguin, Vauquelin, Guyton de Morveau, and others, as contributors, from 1789 to 1800, of articles on the greatest variety of chemical subjects; qualitative and quantitative analyses of minerals and mineral waters, studies of the chemical properties of elements and of their compounds, the chemistry of plant life and animal life, proximate analyses of some organic substances, the preparation of pure salts of various kinds, the illuminating power of different oils, besides the discussions on phlogiston, which were of course a prominent feature in the chemical literature of that period when this theory was receiving its death blows at the hands of Lavoisier. Books on chemistry were published, such as *Methode de Nomenclature Chimique*, *Traité de Chimie*, *Essai de Statique Chimique*, *System des Connaissances Chimique*, *Philosophie Chimique;* and in that same period the *Annales de Chimie* was started. In Germany there was Richter, author of *Anfangsgründen der Stöchiometrie*, *der Messkunst Chemischer Elemente*, and "*Ueber die neueren Gegenstände in der Chemie*," in which he established by his own researches "the doctrine of proportions by weight, and showed that acids combined with bases to form salts, and developed the law of neutralization." There was also Klaproth, the first professor of chemistry in the University of Berlin, who developed especially quantitative analysis, established by his improved methods the composition of many minerals, and discovered uranium, titanium, and zirconium. In Sweden there was Scheele, who made a multitude of important contributions to chemistry, of which even a very imperfect enumeration would take too much of my time; and Bergmann, eminent as an analytical chemist and for his researches in analytical chemistry.

In England there was Cavendish who established the composition of water, and of nitric acid.

We pass on to the next decade, 1800–1809, when in England Sir Humphrey Davy first appeared prominently as a discoverer in chemistry, and published his account of the isolation of the metals potassium and sodium, and Dalton with his first developments of the atomic theory;

when in Sweden there was the great Berzelius, who, from 1807 on, devoted his entire energy to one great aim, the development of the atomic theory, and the first volume of whose *Lehrbuch* appeared in 1808; in France, Gay Lussac who, in 1808, announced the law of combination of gases by volume; Thenard, beginning in 1807 his investigations on the compound ethers; and Proust (really in Madrid, whither he went from France), who, in the last year of the preceding decade, began his fight with Berthollet, contending for eight years for the constancy of proportion in the composition of chemical compounds.

Surely something of the spirit of this great work going on in Europe should begin to make itself felt across the Atlantic, even though the communication between the New World and the Old was still so difficult and narrowly limited. But there is practically nothing recorded in the only journals to which I have access, those already named, and there is good ground for believing that nothing important was done. Priestley was still contending for phlogiston with Dr. Morehouse and Dr. Mitchell, and performing some experiments of small account compared with what was being done abroad; such as "Observations on the discovery of niter in common salt which had been previously mixed with snow," and "Transmission of acids, etc., in the form of vapor over several substances in hot tubes;" "Production of air by the freezing of water." Robert Hare, jr., first appears in an "Account of fusion of strontites and volatilization of platinum," and B. Silliman in an "Analysis of a meteoric stone." Also, there is mention of perhaps the first soil analysis in America, under the title "On the substances which constitute the mineral soil of the environs of Boston."

All records fail me of any work done in the next decade, nothing being given in the above Transactions, till the appearance of Silliman's Journal in 1819; the eight short papers of that year, one of them by Dr. Hare and the others by Silliman, only one to four pages each, and relating to unimportant topics, merit no further mention.

In the *twenties* over seventy papers of chemical import were given in Silliman's Journal, of which sixteen, mostly by Robert Hare, and very short with but four or five exceptions, referred to new forms of chemical apparatus or to reagents; seventeen, from one to seven pages in length, related to analyses of minerals; there were two papers on the present state of chemical science and three on atomic weights, or points in chemical theory; other topics were generally of no special interest. In the Transactions of the American Philosophical Society, and in the Journal of the Franklin Institute which was started during this period, and the Proceedings of the Lyceum of Natural History of New York, were nine short papers, chiefly on analyses of minerals.

In the *thirties* about one hundred papers appeared in Silliman's Journal and the Journal of the Franklin Institute, nearly all of which were short—less than five pages long; but the character of the work, so far as indicated by the topics, was becoming higher; twenty-six papers

related to studies of the properties of chemical elements or their inorganic compounds, and fifteen to studies in organic chemistry—none of them very deep, perhaps, but still on a higher plane than heretofore; only fifteen related to analysis of minerals or mineral waters, six or eight to technical matters, and seven to analytical methods; the remainder were on miscellaneous topics, mostly of subordinate importance. About twenty-five of the whole number of papers were contributed by Dr. Robert Hare, many of them very short, and, as in previous years, on new forms of apparatus or new methods of preparation of substances, in the devising of which he appears to have been very ingenious. No other single writer was so prominent in the records of either this or the preceding decades.

In the *forties* (1848), a new periodical was added, the *Transactions of the American Association for the Advancement of Science.* Furthermore, original work in chemistry took a wonderful start; and well it might; for such names appeared, familiar enough to some of the oldest of us, if not to the younger men in my audience, as W. B. and R. E. Rogers, the first of whom afterwards took an important part in the organization of the Massachusetts Institute of Technology; J. Lawrence Smith, C. U. Shepard, John W. Draper, T. Sterry Hunt, E. N. Horsford, and W. Gibbs, many of whom had received their inspiration in the laboratories of Germany. Smith studied under Orfila, Dumas, and Liebig; Draper, a native of England, under Dr. Turner, of the University of London; Horsford under Liebig; Dr. Gibbs under Rammelsburg, Rose, Liebig, and Regnault.

Over a hundred papers appeared in the periodicals above named, and, while greater length does not necessarily mean much, nevertheless when papers of ten, fifteen, twenty pages or over, are the rule, rather than papers of two to four or five pages, it is not far out of the way to suppose that when such men as these I have named, and Silliman and Hare, write them, they are not made up of padding. Classifying these hundred or more papers roughly, about forty-three of them may properly be called purely scientific papers on inorganic chemistry, twenty on organic chemistry, twenty on analyses of minerals and waters, ten on analytical chemistry, and the rest on technical or other topics more removed from pure science. J. Lawrence Smith contributed eight of these papers; Hunt, ten; the Rogers brothers, eight. Dr. Hare was still prolific, contributing eight papers. Eight of the papers were purely theoretical, such as those on "The idea of an atom suggested by the phenomena of weight and temperature;" "Allotropism of chlorine as connected with the theory of substitution;" "Anomalies presented in the atomic volumes of phosphorous and nitrogen;" "Principles to be considered in chemical classification;" "Theory of compound salt radicals."

In the *fifties* about one hundred and seventy papers were published, against one hundred in the preceding decade, classified as follows: purely scientific, inorganic chemical work, about sixty; organic, eight;

analytical, twenty three; mineral analyses and studies, forty; technical subjects, nineteen; miscellaneous, eighteen. Several of these papers are theoretical studies; as, "Comparison between atomic weights and chemical and physical action of barium, strontium, calcium, and magnesium, with some of their compounds:" "Numerical relations between the atomic weights, and some thoughts on the classification of the elements;" "Theoretical relation of water and hydrogen;" "Apparent perturbation of the law of definite proportions in compounds of zinc and of antimony;" "Rational constitution of certain organic compounds," etc. New and well-known names appearing prominently were those of Genth, Mallet, Cooke (J. P.), Brush, and C. M. Warren. Robert Hare's name disappears. Cooke, in his article, above mentioned, on the numerical relations between the atomic weights, etc., classifies the elements in six series similar to the series of homologues in organic chemistry; in each series the difference between the successive atomic weights is a multiple of some whole number, this number being different for the different series. He shows that the properties of the elements in each series follow a law of progression; the numerical law for the progression in the specific gravity is given; and when a sufficient number of determinations shall have been made of such other properties as are capable of measurement, he predicts that numerical laws for each of these kinds of variation can be ascertained. Thus he looks forward to a perfect science of chemistry in which we shall be able to foretell with certainty the properties, not only of undiscovered elements in any given series, but also of the compounds of these elements. There are many correspondences between his classification and that of Mendeléef, and as above shown, he forshadows the idea, already realized with the aid of Mendeléef's classification, of the possibility of locating and describing hitherto unknown elements. Hunt contributed seventeen of the papers, largely given to the analysis and constitution of minerals; indeed, the examination of American minerals was a very prominent feature of the chemical work of this decade, as shown by the number of papers on the subject. J. Lawrence Smith and Mallet did the largest part of their work on this line, and the former made an important contribution to the methods of anlaysis of minerals, in his new process for the separation of the alkalies. It was in this decade that the famous work appeared of Gibbs and Genth on the Ammoniao-Cobalt Bases, covering 59 quarto pages of the Smithsonian Contributions to Knowledge—the longest single article that had, up to that time, appeared on a chemical research. A re-determination of the atomic weight of lithium and of antimony was made by Mallet, the first work of this kind done by an American chemist. It may well be said that this is the first decade of chemical research in this country which has some prominent and important characteristics to distinguish it from the others that preceded it.

In the *sixties* about two hundred and fifteen papers were published,

against one hundred and seventy in the fifties, of which ninety pertained to general inorganic chemistry, forty to organic chemistry, twenty eight to methods of analysis and new forms of apparatus for analytical purposes, thirty to the analysis of minerals and mineral waters; seven were on technical subjects, fourteen on meteorites, four on agricultural chemical topics, and three on animal or vegetable physiological chemistry. More attention was given in this decade than in the preceding one to more purely scientific studies in general chemistry, for on inorganic and organic chemistry together there were one hundred and thirty papers, against only sixty eight in the earlier period, while analyses of new minerals, also genuine scientific work, were almost as numerous as before. The most prominent contributor was Lea, nearly all of whose papers, over thirty in number, were on important topics in both inorganic and organic chemistry. Cooke and Horsford, of Harvard, and Gibbs and J. Lawrence Smith contributed important papers, as did also Hunt; Warren made some important contributions in organic chemistry. Other contributors were Brush, Ordway, Crafts, and Wetherill. Hinrichs first appeared with his theoretical essays, which some of us have perhaps attempted to master and assimilate. Of the papers on general inorganic and organic chemistry, about forty were from ten to thirty pages in length, indicating, at least as to quantity of material to be communicated, research studies of considerable length. The proportion of such long papers was very much smaller in the preceding decades.

There is much work deserving special mention in this decade, such as Clark's "Constants of Nature," a collection of all the reliable determinations of specific gravities, boiling points, melting points, specific heats, and expansion by heat, and covering 450 octavo pages of the *Smithsonian Miscellaneous Collections;* Warren's Monograph, of 100 quarto pages in *The Transactions of the American Academy of Arts and Sciences*, on "A new form of apparatus for fractional condensation of volatile liquids free from objections incident to the methods in use;" and "Researches on volatile hydro-carbons;" also, his papers on "A new method for combustion in a current of oxygen gas alone, without the use of cupric oxide;" and on "The analysis of organic substances containing sulphur and chlorine."

As one result of his work on the hydro-carbons, Warren showed that the elevation of the boiling point for an increment of CH_2 in homologous series is 30°, or much larger than was hitherto supposed; and that in certain other series derived from the benzole series, differences in boiling points for CH_2 added or removed are much smaller than 19°, Kopp's figure.

Worthy of mention is Lea's attempt at a classification of the elements in several groups, the members of each group differing by 44–45, showing that "the elements thus grouped consist of bodies whose properties are analogous—and that this classification is in harmony with the

distinguishing characteristics of the substances classified." One such group starts with Sb, 120·3; As, 75; P, 31; N, 14; Sn, 59, and Pb, 103·5. Another comprises Hg, 200; Cd, 112; Zn, 65·5, and Mg, 24·4; all the members of this last group are in one of Mendeléef's groups, and the first four members of the first group are also in another of Mendeléef's. This grouping is founded on a broader basis; but Lea's was published thirty years ago, in 1860.

Gibbs showed by reference to the volumetric relation of gaseous compounds that if the proposed new atomic weights, 16, 12, and 32, be accepted for oxygen, carbon, and sulphur, the atomic weights of at least fifty other elements must be doubled, and as he is not a man to fail to give due credit to others it is fair to infer that he was the first to call attention to this necessity. Lea's work on the ethyl bases, as he calls them, diethylamine, triethylamine, etc., is comprised in several papers, in which he gives a very full account of their reactions and a new method of separating them by picric acid. Ordway gave a very exhaustive paper on soluble glass, its chemistry and applications; Gibbs and Lea also made extensive researches on the platinum metals, and very notable are the many contributions made by Gibbs on improvements in methods of analysis. Everything coming from his laboratory was reliable, and there was much of it. Hunt published three papers on the chemistry of mineral waters, in which, on the basis of certain general principles laid down, and of a number of analyses of waters of the Champlain and St. Lawrence basins, he attempted to trace the history of these waters and account for their origin, and in another paper he attempted also to trace out the origin of the dolomites. Crafts, with Friedel, by results of research on the silicic ethers, proved, as he thinks, convincingly the tetratomic character of silicium. Gaffield's interesting researches on the action of sunlight on glass were made in this decade. Gibbs made a very valuable contribution to the resources of physical chemistry by a calculation of the wave lengths of the lines of a large number of the elements, from measurements made by Angström and Ditscheiner, and Huggin's scale of wave lengths of 1,000 lines. Goessman discussed in a careful and thorough manner the origin of the salt beds and the composition of the salt and the brine of the ocean water.

Three notable books appeared in this decade, Cooke's "Chemical Physics," Storer's "Dictionary of Solubilities," and Wormley's "Micro-chemistry of Poisons."

In the *seventies*, about 240 papers were published, a part of them in three new periodicals. The American Institute of Mining Engineers issued its first volume of Transactions in 1871. Methods of chemical analysis naturally occupied much of the attention of the chemical members of this institute. The *American Chemical Journal* and the *Journal of the American Chemical Society* made their first appearance in 1879. This society was established in 1877 and published two volumes of

Transactions prior to the issue of the first volume of its journal. Dr. Chandler's *American Chemist* also appeared in this decade.*

Eighty of the papers published referred to general inorganic chemistry; 47 to organic chemistry; 57 to analytical methods and apparatus; only 13 to minerals and mineral waters, and the same to technical subjects; 21 short papers were on meteorites; agricultural chemistry had 14 papers; physiological chemistry 5; and sanitary chemistry 2. Analytical chemistry was very much more prominent in the work of this decade, and in fact than at any time before it; methods of agricultural chemical analysis, as well as of analysis pertaining to the mining engineering interests, especially of iron and steel, received special attention. The prominent contributors were M. C. Lea, J. Lawrence Smith, Gibbs, Remsen, and Clarke; there were 130 writers in all, of whom only 14 contributed 5 or more papers, and only 2, Lea and J. Lawrence Smith, contributed over 10 papers; but many of these papers were short. In mass and importance of material published, Gibbs, Clarke, Mallet, and Remsen ranked as high as the more frequent contributors, especially if they receive the credit due them for work done in their laboratories, although published in the names of their assistants or students. The beginning of Chittenden's extended work in physiological chemistry appeared in this decade. Remsen, C. L. Jackson, and A. Michael also became prominent as leaders in research in organic chemistry. Gooch, besides giving us his crucible for filtration, published a valuable work on the determination of phosphorus pentoxide. Gibbs began his long and difficult research on complex inorganic acids, of tungsten, and molybdenum. Clarke traced out some new relations between the atomic volumes of the elements. Hilgard began his work on the methods of analysis of soils, in which he is now the universally recognized authority. J. W. Draper showed that the diagram given in so many works at that time, and occasionally even now, exhibiting unequal distribution of heat and actinism in the solar spectrum is misleading—that, on the contrary, the heat and chemical power are as great at one end of the spectrum as at the other, the diffraction spectrum showing no such inequality as the diagram represents. Lea continued his research on the action of light on silver salts and also made new determinations of the atomic weights of nickel and cobalt. J. Lawrence Smith established the presence of a solid hydro-carbon and free sulphur in meteorites. Cooke made new determinations of the atomic weight of antimony.

While there are single researches in the preceding decade of higher importance than any that appear in this, a careful comparison of the whole amount of work done might show that there was little difference in the real advance made in the two decades.

*This journal was begun in July, 1870, and completed seven volumes, ending in 1876. It had been preceded by an American reprint of the English *Chemical News*, with an American supplement.

In the *eighties* we see an enormous advance in chemical work. One new chemical periodical appeared, the *Journal of Analytical Chemistry*.

Exclusive of papers on the examination of foods and drugs in the Reports of Boards of Health of three or four States, and of papers in Reports of Agricultural Experiment Stations, the whole number published was about 875, and inclusive of papers excepted as above the total would certainly not be less than 900, or more than three and a half times as many as in the preceding decade. About 130 of these papers related to general inorganic chemistry; 255 to general organic chemistry; 283 to analytical chemistry; over 50 to agricultural chemistry, 25 to technical chemistry; 30 to physiological chemistry; 33 to analyses of minerals and mineral waters, and also 33 mostly very short papers, to analyses of meteorites. The amount of solid work on these several lines may be indicated in a measure by the length of the papers; a paper of 1, 2, or even 3 pages would as a general thing represent investigations of minor importance, and comparatively little actual work, although there may be some exceptions to the rule. Comparing in this respect the 3 leading lines of work, general inorganic chemistry, organic chemistry, and analytical chemistry, about 60 per cent of the papers in analytical chemistry are more than 3 pages long, while only 22 per cent of the papers in inorganic chemistry, and 19 per cent of those in organic chemistry, exceed that limit.

About 380 chemists contributed these papers, of whom, however, 258 appeared but once or twice in the whole decade. The most frequent contributors were Clarke, Chittenden, Gibbs, H. B. Hill, Jackson, Morse, Michael, Mabery, Mallet, Remsen, E. F. Smith, and Wiley. Several valuable contributions were made by others, who published fewer papers, and in some cases very important ones.

The most notable feature in the work of this decade is the great amount of work in organic chemistry, done especially under the lead of Remsen, Jackson, and Michael, most of which seemed to find its natural way to the public through Remsen's own journal. In these times, when the *Berichte*, Liebig's *Annalen*, *Journal für Praktische Chemie*, *Monatshafte*, and the *Journal of the English Chemical Society* are giving us every year their 1,500 pages and more of papers on research in organic chemistry, there are at least some of us who are not only not conversant with this work, our lines of study being in other directions, but are each year getting more and more hopelessly out of touch with it. As one of those I would not presume to pass judgment on the value of the researches in organic chemistry that are now being made in this country; but we can be confident that it is not such work as an American need be ashamed of. And I am sure we all rejoice that through these investigators our own country is contributing a large share of worthy research in this great branch of chemical science.

In inorganic chemistry, Dr. Gibbs continued his work into this

decade on the complex organic acids. Morley contributed his masterly papers on the analysis of air and his work on the atomic weight of oxygen; Becker, his digest of investigations on determinations of atomic weights since 1814, occupying 270 pages of the Smithsonian *Miscellaneous Collections;* Clarke gave his re-calculations of the atomic weights; M. C. Lea, his discovery of the allotropic forms of silver; Cooke and Richards, the re-determination of the atomic weights of oxygen and hydrogen; Mallet, his revision of the atomic weight of aluminum and determination of the molecular weight of hydrofluoric acid; Craft's, his determination of the vapor destiny of iodine, with results differing from those of both Deville and Troost, and Victor Meyer, and his paper on the vapor density of permanent gases; and Warder, some of the first beginnings of work on physical chemistry.

I have had pointed out to me by a competent authority as the most significant papers in organic chemistry, "Oxidation of substitution products of the aromatic hydrocarbons," and "Investigations on the sulphinides," by Remsen and his pupils; "Researches on the substituted benzyl compounds," by Jackson and his pupils; "Furfurol and its derivatives," by H. B. Hill, and "Researches on allo-isomerism," by Michael and his pupils. Other leaders in this organic work were Mabery, L. M. Norton, and W. A. Noyes.

In analytical chemistry nothing more prominent appeared than Mallet's most valuable and exhaustive work, in the report of the lamentably short-lived U. S. Board of Health, on "The determination of the organic matter in potable water" and Morley's on "The analysis of air." Analytical chemistry was much advanced along certain technical lines by the work of the Association of the Official Agricultural Chemists, begun in 1884, and by co-operative work on the analysis of iron and steel, published in the transactions of the Institute of Mining Engineers.

In physiological chemistry, Chittenden continued with Ely and others the important work begun in the preceding decade, and published valuable papers on the digestive liquids and the products of their action on the proteids. In sanitary chemistry the work begun by the lamented Nichols in the seventies was carried further in this decade by Mallet in the paper on the determination of organic matter in potable water, already referred to, and the valuable papers by Leeds on potable water supplies, in reports of the New Jersey State Board of Health and the Journal of this society. A large amount of work on the examination of foods and drugs was done under the supervision of the boards of health of a very few States, notably Massachusetts and New York, and of certain cities.

In agricultural chemistry, under the generous provision made by the U. S. Government by an act passed in 1886, giving $15,000 annually to every State in which an agricultural college was established under

the act of 1862, and the no less generous provision made by some of the States themselves, a very large amount of work has been done. So close are the relations of chemistry to agriculture, that the opening and liberal equipment of a chemical laboratory for special work was among the first steps taken, on the establishment of each agricultural experiment station under this grant; thus at present a chemist, with often one or more assistants, is exclusively engaged in each State in agricultural chemical investigation. Under the liberal appropriation made also by the Department of Agriculture for chemical investigation, more liberal than by any other Government, a large amount of valuable work has been done at Washington. In the outcome of these various provisions may be included Atwater's papers on the sources of the nitrogenous food of the plant, Richardson's on the composition of American cereal grains, the work of Jordan, Armsby, and their asso. ciates on the digestibility and feeding value of fodder materials, and Hilgard's continuation of his work on soil analysis. Many papers were published on improvements in methods of agricultural chemical analysis, and a very large amount of routine work was done in the examination of commercial fertilizers for the purpose of protecting the consumers from fraud. In all this a prominent part was taken also in this decade by Johnson, Goessman, Jenkins, Babcock, Osborne, and others.

Thus my history closes; a hurried one, and therefore imperfect, but nevertheless giving, I trust, something of an idea of what we have come to in this country, from very small beginnings. From about eighty papers in the twenties, the first decade in which any work of importance was done, to over nine hundred in the eighties is great progress: and the progress justly appears greater, when the character of the work is also taken into account. In the twenties the papers were mostly about the analysis of minerals, or new forms of apparatus or new reagents—and mostly very short papers—and in general much below the grade of work that was going on in Europe; in the eighties the work was on the same lines and of the same order as that done elsewhere, and as well as that, rich in important results.

But there is room for further progress still, much of it, before we in this country shall accomplish as much as our brother chemists do in Europe,—before our Chemical Society shall, if it publishes a journal, be able to send out annually such a volume as the Berlin Society does, to say nothing of what appears in other German periodicals.

What are our prospects, and what our means for doing this? This kind of work is done at the universities of Germany and her technical schools. We have universities; more of them, so-called, than Germany has; we have a few technical schools of a high order, and innumerable colleges. These universities and technical schools have their chemical laboratories, as have also many of the colleges. Every State has its agricultural experiment station, with a working chemical laboratory. So far then, as concerns laboratories and men in charge of

them more or less specially educated as chemists, there is abundant provision. Every one of these universities, colleges, and advanced technical schools has a double mission to perform, if it does the whole work that is expected elsewhere in the world, of institutions giving higher instruction. One of these missions is to teach—to impart knowledge that is already a part of the world's possession of knowledge, to the students who are seeking it, now in larger numbers than ever before. The other mission is to gain new knowledge—to add to the world's stock of it. Here and there is seen a man of wealth, and scientific tastes and acquirements, and an aptitude for research, who investigates in his own private laboratory, and does good work there; but such a combination is rare. These higher institutions of learning are to be in the future, as they have been in the past, the fittest places, and indeed almost the only places, for the making of both investigators and investigations.

Why is it, with so many of these institutions as we have, making claim to this high rank in our system of instruction, that we fall so far short of contributing our full share of the world's acquisition of new knowledge, year by year? The first and perhaps most important reason is that those upon whom this work devolves, and who would be glad to do it, have no time for it. Their work of instruction, often comprising many branches of science, uses up all their energy. This unfortunate condition of affairs is chargeable, to a large extent, to the multiplicity of colleges with endowments inadequate for the performance of the whole work of a college. It may be fairly said that no institution of learning is fully worthy of being called a university, or a college of high rank, that does not provide teachers enough, so that each one has spare time for investigation. There is room for improvement, in this respect, even in some of our largest universities. It is not always practicable for an outsider, such as the average trustee is, to get so thorough an acquaintance with the inner workings of the several departments, as to understand how most of a teacher's time may be consumed in the management of the petty details of a laboratory full of students, provided that he does his duty there.

Secondly, given the time when this important feature of college and university comes to be properly appreciated, will there be means for the work? There can be little doubt that they will then be provided; if not in any other way, when it appears that there are men ready and competent to carry on valuable investigations, but who can not for want of means and appliances, new funds for the promotion of such work may perhaps be added to those already in existence, such funds as the Elizabeth Thompson science fund, now amounting to $27,000, the Bache research fund, and the Wolcott Gibbs fund for chemical research.

Given time and means, have we the men in this country for creditable scientific research? I think that such an answer to this question as is indicated by the records of the chemical research in the decade

from 1880 to 1890 is most encouraging. Great investigators like great poets, like men great in anything, are born not made; born, may we not truly say, out of the spirit of the country and the period in which their great works are done. But when born they must be nurtured, and the place for their nurture is the university. In this sense the university must make the investigator as well as the investigation. In the land where the spirit of investigation is rife there will be the most material out of which to make investigators; and there too will men and women destined to be such be most sure to drift into the line of life work for which they are best adapted and receive the best training for it.

It seems to me that the relations of our society to this matter of the furtherance of chemical investigation in this country are of vital importance; that if it does not appear in its stated meetings or the meetings of its sections scattered throughout the country that it is alive with the spirit of research, it will fail to establish its reason for being; and membership of it will be of little advantage to anybody, and that the society itself will be of little service to the country.

THE HIGHEST METEOROLOGICAL STATION IN THE WORLD.*

By A. Lawrence Rotch.

By the will of Mr. Uriah A. Boyden, a considerable sum of money was left in 1887 to Harvard College Observatory to aid in the establishment of an observatory "at such an elevation as to be free, so far as practicable, from the impediments to accurate observation which occur in the observatories now existing, owing to atmospheric influences." Preliminary stations were accordingly established in Colorado and in California, provided with meteorological and astronomical instruments to test the meteorological as affecting the visual conditions. From these observations it was concluded that the selection of a proper site was by no means a question of elevation alone, and it was thought desirable, from theoretical considerations, to secure a location within the tropics.

An expedition was accordingly sent to South America, where a station on Mount Harvard, near Lima, Peru, at an elevation of 6,600 feet, was occupied for a year, and other sites further south were examined by the Messrs. Bailey. Owing to the remarkable clearness and steadiness of the air at Arequipa, Peru, it was finally decided to locate a permanent station there, and, under the direction of Prof. W. H. Pickering, land was purchased outside this city and the observatory buildings were erected in 1891. The city of Arequipa is situated above a desert about 80 miles from the Pacific Ocean, in a little oasis formed by a river valley at the foot of the Cordillera. The observatory is built upon the crest of a hill overlooking this valley, about 400 feet above the city and 8,050 feet above the sea. It stands approximately in 16° 22′ S. latitude and in 71° 22′ W. longitude. Eastward the extinct volcano of Pichu-Pichu rises to a height of 18,600 feet; northeast, and 10 miles distant, is the quiescent volcano of the Misti, 19,200 feet in altitude, and 12 miles north rises Charchani, 20,000 feet high, which is always snow-capped.

The meteorological station, forming the subject of the article, is situated on the latter mountain just below the permanent snow line.

* From *American Meteorological Journal*, October, 1893, vol. x, pp. 282–287.

Southeast of and about 3,400 feet below the summit is a *cirque*, forming a plateau less than half a mile square, which drops several hundred feet in a precipice on the south. Near the brink, at an elevation of 16,650 feet above the sea, is the meteorological station. The instruments are contained in a small louvred shelter, 22 inches square, placed on a rock, and comprise the "exposed" and maximum and minimum thermometers of the U. S. Signal Service pattern, a self-recording aneroid barometer, and two self-recording thermometers, all of the well-known Richard *frères'* construction. The record cylinders revolve in rather more than seven days, but as the clock movements operate during ten or twelve days, records for this length of time can be obtained, since, as the cylinders do not turn in an even number of days, the diurnal variations of pressure and temperature during the second week are not superposed upon those of the first week. Near the shelter has been erected a stone hut, where the person who ascends the mountain to care for the instruments can spend the night if necessary. The ascent of 8,600 feet from the observatory can be made by mule in about eight hours; and though it is intended to have one of the assistants visit the station each four weeks, regular ascents have not been practicable; consequently, during the year the station has been equipped, only portions of ten months' records could have been obtained, and unforeseen stoppages of the self-recording instruments have further reduced the quantity of complete records to eight. The automatic traces of atmospheric pressure and air temperature are controlled by a mercurial barometer carried up by the observer and by readings of the "exposed" and the maximum and minimum thermometers, the two latter showing the extremes of temperature which have occurred since the last visit. The distance in an air line from the station to the observatory is about 11 miles, and such is the transparence of the air that on a large white disk, which has been placed on the edge of the plateau, a black spot, 1 inch in diameter, can be seen with the 13-inch telescope at the observatory.

The meteorological equipment of the observatory is quite complete; and besides the ordinary instruments for direct observations there are the self-recording barometer and thermometer, of Richard *frères*, an anemograph of the Signal Service type, and photographic sunshine recorders of the form devised by Prof. Pickering. Direct observations three times a day, at 8 A. M., 2 and 8 P. M., with frequent night observations at 2 A. M., have been made during two years but have not been reduced. The results of the observations at both stations will be published later in the *Annals of Harvard College Observatory*, and their discussion will no doubt add greatly to our knowledge of mountain meteorology. Anything more than a brief summary of some of the most salient features would, therefore, be out of place here. From data for the year 1891–'92, cited by Prof. Pickering in *Astronomy and Astro-Physics*, May, 1892, it appears that the atmospheric pressure and

air temperature at Arequipa are very uniform throughout the year. The highest barometer reading was 22·676 inches on August 17, and the lowest, 22·472, on January 19. The maximum thermometer reading, which was exceptionally high, was 79° on June 3, and the lowest, 38·5°, occurred eight days afterwards. Although the temperature never descended to freezing, yet there are occasional frosts, and in the clear season the intense radiation causes thin ice to form. The clear season begins about the 1st of April and continues with scarcely an interruption until the 1st of November. During January and February, 1892, most of the rain fell, amounting to 2 or 3 inches. In February, 1893, 4 inches fell in a single storm, but this appeared unprecedented and did great damage. The mornings are generally bright throughout the year, most of the rain falling in the afternoon or evening. Excepting during the rainy season, the air is exceedingly dry, relative humidities of 35 per cent having been recorded in March, 1893. The wind, as at low elevations, reaches its highest velocity in the middle of the day, and it is generally calm at night. For the year above quoted, the highest velocity, 17 miles per hour, occurred in December. Soon after sunrise a strong wind blows down from the mountains to the northeast, after which the wind shifts, decreases in velocity, and resumes its normal course.

The diurnal periods of the atmospheric pressure and the air temperature are interesting on account of the small amplitude of both, and the phases of the former. Taking the barograph records for December at Mollendo at sea level, at Arequipa (8,050 feet), and at the camp on Charchani (16,650 feet), the respective diurnal amplitudes are 0·1 inch, 0·07 inch, and 0·03 inch. Whereas, at the sea-level station, the chief minimum and maximum occur about 5 P. M. and 11 P. M., respectively, with secondaries at 4 A. M. and 9 A. M.; at Arequipa, the chief minimum occurs about 5 A. M., and the secondary minimum about 4 P. M. The night maximum, which is also the chief one, occurs at about the same hour at both stations; but at Arequipa the secondary day maximum is advanced to about 1 P. M.

Not enough records at the Charchani station have been reduced to determine definitely the pressure period, but there appears to be a double daily maximum and minimum, whose times correspond in general to those at Arequipa. The noon and night maxima have nearly equal intensities, but the morning minimum is deeper than the afternoon one as at Arequipa. These facts are the more interesting because some preliminary observations by M. Vallot, on the summit of Mont Blanc (altitude 15,780 feet), showed but a single maximum at about 1 P. M., and a single minimum about 4 A. M., with only a tendency toward a secondary minimum late in the afternoon. At Chamounix, in the valley, the diurnal period is nearly the same as at Arequipa, so that the form of the curve at the Charchani station may be partly due to the

situation of the instrument in a depression on the flank of the mountain, the topography of a station being known to influence these periods.

As has been stated, the permanent snow line is above the camp on Charchani, but last March, at the close of the warm and wet season, there were 2 feet of snow on the plateau. Snow covered the ground down to 14,700 feet, while ice formed at night as low as 11,500 feet. On the night of March 9, the temperature of the air, in the shelter at the Charchani camp, fell to 20·5°, while over the snow, radiation lowered it to 14°. The temperatures do not seem to be greatly influenced by the seasons, and the range from January to March, 1893, was from 13° to 46° F. The decrease of temperature in the 8,600 feet of air between the camp and observatory, as deduced from nearly simultaneous observations at 8 P. M. and 8 A. M. on March 9 and 10, 1893, was 1 degree for 284 feet in the morning and 1 degree for 309 feet in the evening, which agrees with similar observations previously made in the tropics. The relative humidity was completely inverted at these times, the evening observations showing 34 per cent on the mountain and 56 per cent at the observatory, while the morning observation gave 56 per cent on the mountain and 36 per cent at the observatory, the changes from nearly complete saturation to great dryness being very sudden at the upper station.

The physiological effects of an ascent to the camp on Charchani, where the atmospheric pressure is reduced to about 16·50 inches, are very marked. This seems to be about the limit to which mules can be driven, and seldom in other places have they been taken so high. Few persons escape the *soroche* or mountain sickness in some of its forms, especially if they stop at night. The effect upon the writer during his eighteen hours' sojourn may be interesting. Though ordinarily sick at lower altitudes, there was here no nausea or severe headache, the usual symptoms of mountain sickness, which may perhaps be attributed to the ascent by mule, without muscular exertion, whereas previous high ascents had generally been on foot. Other symptoms however manifested themselves in abnormal excitability and restlessness which made sleep impossible, and by a lapse of memory as well as in a want of sequence of ideas. The appetite remained good, and the writer's physical condition made it probable that he could have climbed higher After a rest of two hours at the hut, the pulsations of the heart were 115, and the respiration through the lungs 25 per minute. These decreased during the night to 88 and 22, respectively, and the temperature of the blood (measured under the arm) from 98·06° to 97·52°, the normals at Arequipa at night being 80, 21, and 97·16°, respectively.

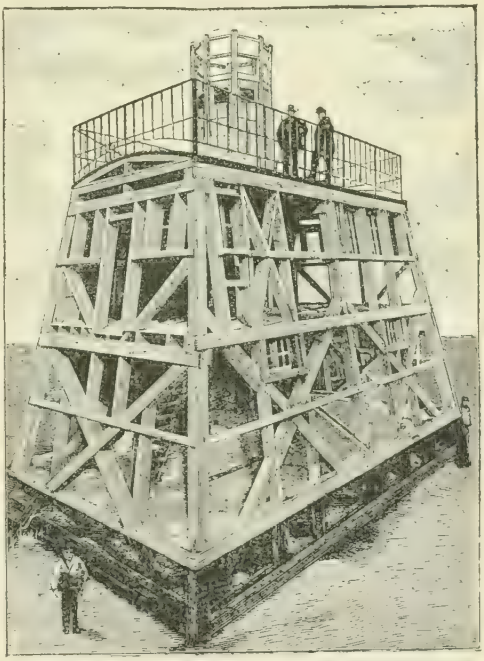
All the meteorological data would be much more valuable if obtained in the free air upon the summit of Charchani. The establishment of a station 3,400 feet higher, however, is a very difficult undertaking, as two unsuccessful attempts have been made by parties from the observatory to climb the steep and snow-covered slope. A thermometer shel-

ter, intended for the summit station, was carried some distance up on one of these occasions. If a suitable site could be selected on the summit of Charchani, and self-recording instruments placed there, it seems feasible to engage an intelligent native to ascend the mountain once a month, or oftener, to keep the instruments in operation, since it is known that some natives are less incapacitated by great altitudes than are foreigners. It is possible that this plan may be carried out by the Harvard Observatory, or, if it is found impracticable, a lower and more accessible peak to the west of Charchani may be thus utilized.

The comparatively elevated temperature and small snow-fall on the high mountains of Peru offer opportunities for the establishment of loftier meteorological stations than are afforded by any other country, and the establishment of such a summit station by the Harvard Observatory would be the crowning of its remarkable series of stations, extending from Mollendo, on the Pacific coast, along the railroad which crosses the desert of La Joya (4,140 feet), reaches the divide at Vincocaya (14,360 feet), and descends the watershed to Puno on Lake Titicaca (12,540 feet). Another series, differing little in horizontal distance, but relatively greatly separated vertically, for which the observatory at Arequipa and the camp on Charchani already furnish steps, would make it possible to obtain data of the greatest value for the progress of meteorology, which is looking more and more to the study of the upper air for its advance; and for this study the mountain summits furnish the only practical method of obtaining continuous records approximating the conditions prevailing in the free air.

THE MONT BLANC OBSERVATORY.*

The project of establishing a meteorological and astronomical observatory on the summit of Mont Blanc has, under the care of M. J. Janssen, of the Meudon Observatory, made considerable progress during this year's summer months. It has been decided to use the snow itself as a foundation on which to rest the building. That this can be done with security was shown by some experiments carried out at Meudon last winter. A miniature mountain was made of snow pressed to the same density as that which is found on Mont Blanc at a depth of 1 or 2 meters below the surface. This being made level at the top, disks of lead, 35 centimeters in diameter and weighing each about 30 kilograms, were placed on the snow, one upon the other. After twelve of these had been piled up, with an aggregate weight of 360 kilograms, they were removed and the depth of the impression measured. It was not more than 7 or 8 millimeters. Thus a structure measuring 10 by 5 meters might safely weigh 187,000 kilograms without sinking into the snow more than a few centimeters.



Mont Blanc Observatory.

The summit of Mont Blanc is formed by a very narrow edge of rock 100 meters long, running from west to east, and covered by snow which is thicker on the French than on the Italian side. The level of this snow has not shown any important oscillations throughout a number of years. To obviate the disturbing effects of the storms which frequently rage around the summit, the building is constructed in the shape of a truncated pyramid, the lower floor being sunk into the snow.

* *Nature*, December 29, 1892; vol. XLVII, p. 204: from *Comptes Rendus*, November 28, 1892.

The rectangular base measures 10 by 5 meters. The upper floor, which will be devoted to the observations, is covered with a flat roof, toward which ascent is made by a spiral staircase leading from the basement upwards through the whole building, and above the flat roof to a small platform destined for meteorological observations.

The whole observatory has double walls to protect the observers against the cold. The windows and doors are also double, and provided on the outside with shutters closing hermetically. The floor is made of double planks, and furnished with trap doors giving access to the snow supporting the observatory, and to the screw jacks placed in position for adjusting the level of the building in case the snow should yield. The building will be provided with heating apparatus and all the furniture necessary to make habitation at such an altitude possible.

Up to the present the observatory has been transported in parts to Chamounix. On the Grands Mulets a cottage has been erected for the use of the workmen and for storing the things destined for the observatory.

On the Grand Rocher Rouge another cottage has been built, only 300 meters below the summit, in which the workers and observers can, if necessary, take refuge. Three-quarters of the materials for the observatory have been transported to the Grands-Mulets (3,000 meters) and the rest to the Rocher Rogue (4,500 meters).

Next year the erection on the summit will be carried out. An astronomical dome, which is to complete the observatory, will also be taken in hand. The work done up to now has been carried out under great difficulties, owing to the fact that everything had to be carried by hand. But no accident has, so far, marred the success.

Dr. Capus, who accompanied M. Bonvalot in his well-known expedition to the Pamir, has promised his assistance for certain observations. But the observatory will be international and open to all observers who wish to work there.

THE OBSERVATORY ON MOUNT BLANC.*

As briefly announced in our notes last week, Dr. Janssen has recently visited the observatory on Mount Blanc. In the current *Comptes Rendus* he gives an account of the expedition from a scientific point of view, and the following is a translation of his description:

We left Chamonix on September 8, at 7 A.M., and arrived at the summit on September 11, at 2:30 P.M. The observatory was then in front of us. This construction has several floors, of which the framework, formed by large and massive beams crossed in all directions in order to insure the rigidity of the whole, produces a deep impression upon the

* From *Nature*, October 5, 1893; vol. XLVIII, p. 549.

One wonders how it has been possible to transport the edifice to this altitude and fix it on the snow. However, if the conditions offered by the hard, permanent, and little mobile snows of the summit are carefully considered, it is soon recognized that the snows are able to support very considerable weights,* and that they will be only slightly amenable to displacements, which will render it necessary to straighten again the construction which has been fixed upon them.

On my arrival I made a rapid survey, and saw that the construction had not been sunk in the snow as much as I had stipulated of the contractors. I do not approve of this. My guides and myself then took possession of the largest underground room. I intended at first to fix the instruments for enabling observations to be commenced immediately, and the provisions were left on the Rocher-Rouge. This circumstance put us in a state of perplexity, for the weather suddenly became very bad, and we had to remain two days separated from the stores. The storm lasted from Tuesday until Thursday morning. Beautiful weather then set in, and I was able to begin the observations.

The observations have for their principal object the question of the presence of oxygen in the solar atmosphere. The academy knows that I worked at this important point during my ascensions to the Grands-Mulets (3,050 meters) in 1888, and at M. Vallot's observatory in 1890.

But the novelty of the observations of 1893 lies in the fact that they have been effected on the very summit of Mount Blanc, and that the instrument employed is infinitely superior to that of the two preceding ascensions. At the first, in fact, a Duboscq spectroscope, incapable of separating the B group into distinct lines, was employed, while the instrument about to be employed at the summit of Mount Blanc is a grating spectroscope (the dispersive piece of which I owe to the kindness of Rowland), with telescopes having a focal length of 0·75 and showing all the details of the B group. This circumstance is of considerable importance, for it may lead to the discovery, in the constitution of the group in question, of valuable elements for measuring in some way the effects of the diminution of the action of our atmosphere as one ascends into it, and, accordingly, to determine whether this diminution corresponds to total extinction at its limits. In fact, we shall learn whether or no the double lines which make up the B group diminish in intensity as their refrangibilities diminish—that is, as their wave lengths increase.

This circumstance may perhaps be employed with profit, if not to measure at least to observe the diminution of the action of the selective absorption of our atmosphere. It has been ascertained that the most feeble doubles fade away one after the other as the atmosphere is ascended—that is to say, as the absorbing action is diminished. Thus, under ordinary circumstances, at the surface of our seas or upon our

* See *Comptes Rendus* for an account of experiments made at Meudon on the resistance of slightly compressed snow. (*Ante*, p. 259.)

plains, thirteen or fourteen doubles can be seen, not reckoning that which is known as the head of B.

But even at Chamonix—that is, at an altitude of 1,050 meters—the thirteenth double is very difficult to make out, and at the Grands-Mulets (3,050 meters) it is only possible to see from the tenth to the twelfth, while at the summit of Mount Blanc I could hardly go beyond the eighth.

It is not to be supposed that we establish a proportionality between the numerical diminution of the doubles and that of the atmospheric action. The law is evidently of a much more complex character. But this diminution, especially when considered in connection with the experiments made with tubes full of oxygen, and able to re-produce the series of atmospheric phenomena to which we have referred, is sufficient for us to conclude that the B group would totally disappear at the limits of our atmosphere. It is remarkable, however, that if we take the coefficient 0·566 that represents the diminution of atmospheric action at the summit of Mount Blanc according to barometric pressures $\left(\frac{0{\cdot}43}{0{\cdot}76} = 0{\cdot}566\right)$ and multiply it by thirteen—the number that represents the doubles clearly visible on the plain—we obtain 7·4 as the result—that is to say, very nearly the number (8) doubles that can be seen be me on the summit of Mount Blanc.

This result is certainly remarkable, but I repeat that, in my opinion, it is only by the comparison with tubes reproducing the same optical conditions as nearly as possible that any definite conclusions will be obtained. These comparative experiments have already been commenced in the laboratory of Meudon Observatory, and they lead to the same result, viz, the disappearance of the groups A, B, and *a* at the limits of the atmosphere. On account of the importance of the question, however, the experiments will be repeated and completed.

The question arises as to whether the high temperatures to which solar gases and vapors are subjected are not capable of modifying the power of selective absorption, and particularly whether the absorption of oxygen which takes place in the sun's atmosphere would not be altogether different from that indicated by the experiments which have been made at ordinary temperatures.

I have already instituted experiments with the idea of replying to this objection. I shall give an account of them to the academy in due course, but I may say that the absorption spectrum of oxygen, either the line spectrum or the unresolvable bands, do not appear to be modified in an appreciable manner when the oxygen is raised to temperatures of about 400 or 500 degrees.

On the whole, I think that observations made on the summit of Mount Blanc give a new and much sounder foundation to the study of the question of the purely telluric origin of the oxygen groups in the solar spectrum, and lead to the conclusions previously stated.

Independently of these observations I have also given some attention to the transparency of the atmosphere of this almost unique station, and to the atmospheric phenomena which are included in such an extensive view, and across such a great thickness. I shall speak of this on a future occasion.

The observatory of course is not completed. There yet remains much to be done independently of interior arrangements and the installation of the instruments; but the great difficulty has been overcome, for we are free to work, and no longer have to reckon with the snowstorms; the rest will follow in due course.

I hope that the observatory will soon be able to offer a much more comfortable sojourn than I have had there; but that will depend upon the weather. Be this as it may, I regret nothing. I strongly wished to see our work in position, and still more fervently desired to inaugurate it by observations which are ever in my mind. I am fortunate at having been able to realize my desires in spite of some difficulties.

RELATIONS OF AIR AND WATER TO TEMPERATURE AND LIFE.*

By Gardiner G. Hubbard,
President of the National Geographic Society.

CIRCULATION OF AIR AND WATER.

It was said in olden times, "The wind bloweth where it listeth, and thou hearest the sound thereof, but canst not tell whence it cometh and whither it goeth."

That which was unknown, science hath revealed. The wind in its currents is governed and directed by laws as fixed as those of the solar system. If a moisture-laden wind passes over the country it leaves the land fruitful; but a dry wind leaves it barren. The currents of air are among the most important factors in the physical geography of our earth, affecting not only soil and climate but also vegetal and animal life.

The winds obtain their moisture through evaporation, which goes on everywhere and at all times; in the equatorial and polar oceans, from the rich cultivated soil and the arid desert, from the valley and the snow-clad mountain. Reclus tells us that the evaporation from the equatorial ocean is from 13 to 16 feet a year. This estimate is confirmed by the U. S. Geological Survey, which found the evaporation from the southern Colorado River to be 102 inches, or nearly 9 feet in a year. The quantity of water evaporated from the land must be very large, as only about two-fifths of the rainfall is returned by the rivers to the ocean. A great part, probably more than one-half of this quantity, is re-evaporated to fall the second and third time as rain.

The movements of the atmosphere depend either directly or indirectly on differences of temperature; without these differences the air and ocean would be stagnant. There is a constant interchange of atmosphere between the equator and the poles. Cool air from the north blows toward the equator, first in a southwesterly, then in a westerly direction, crossing the Atlantic about the tropic of Cancer. Cool air from the south blows in a northwesterly and westerly direction, and crosses the Atlantic near the equator. The difference of solar acces-

* Address before World's Congress at Chicago, July, 1893. From *The National Geographic Magazine*, vol. v, pp. 112–124.

sion between the equator and the poles gives the northward and southward motion to these currents; the revolution of the earth on its axis gives the westerly motion.

These air currents are the great trade-winds which wafted Columbus across the Atlantic and Magellan across the Pacific. The trade-winds of the northern Atlantic are about 20° in width from north to south; those of the southern Atlantic are not quite so wide. These winds oscillate northward in August and southward in February, following the sun. Between the trade-winds of the north and the trade-winds of the south there is a zone of calm.

While the winds blow over the land as well as over the ocean, their movements, interrupted by hills and mountains and affected by temperature, lose that broad sweep and uniformity so characteristic of the ocean.

Return currents of warm air blow across the ocean from the torrid zone toward the northeast in the northern Atlantic, and toward the southeast in the southern Atlantic. The trade-winds, or equatorial currents, blow around the world from east to west; the polar currents blow from west to east.

The great ocean currents follow the same general courses as the wind system. Their movements are initiated by differences in density, caused chiefly by temperature and by evaporation; yet the larger part of the motive power is derived from the wind. These movements have been ascertained by years of observation on vessels in every ocean, sea, and gulf, by the cumulative evidence of drifting objects, some of which have had their influence on the spread of vegetal and animal life and even civilization itself, and by the researches of scientific exploring expeditions to polar regions and remote islands. These oceanic movements are as well understood as those of the great atmospheric ocean above us.

When water has acquired its movement, the configuration of the bottom of the ocean and of the shore line, the rotation of the globe on its axis, and the direction and velocity of the wind modify its movement.

SOUTH AMERICA.

By this circulation the equatorial waters of the Atlantic blow across that ocean, impinge against the coast of South America, and are deflected northward and southward. The southeasterly trade-winds blowing over it become surcharged with moisture and pass directly up the valley of the Amazon, watering the earth with frequent rains for 2,000 miles to the foothills of the Andes, where some of this moisture is deflected by the mountains southeastward to water southern Brazil; the remainder ascends the slopes of the Andes until it is condensed and falls as rain and snow, and only dry winds blow across the comparatively narrow plains between the Andes and the Pacific. The vapor from the Atlantic falling in rain over the valley of the Amazon and along the eastern slope of the Andes and the Cordilleras flows back

to the ocean through the Orinoco, the Amazon, and la Plata, and makes the interior of South America one of the richest countries of the world.

The Amazon, a great mediterranean sea, as it is often rightly called, is projected into the heart of the continent. Its total fall from the foothills of the Cordilleras to the ocean is not over 300 or 400 feet, affording for the largest vessels uninterrupted navigation and innumerable harbors for 1,500 miles into the interior and 1,000 miles farther for smaller vessels. The aggregate navigable waters of the main stream and its tributaries are estimated at 50,000 miles. The moist winds abundantly water the valley and modify its climate. Their influence in tempering the climate is felt directly more than 1,000 miles up the valley, and indirectly still farther, through the shadows thrown by the clouds and through the rainfall and the cooling effect of the drops of rain falling from a high altitude. It is from 8° to 10° cooler than on either side of this rain belt, and it is more healthful than other equatorial regions. The tropical woods are so thick and the creepers and undergrowth so luxuriant that animal life is almost entirely confined to the trees above and the waters below. Nature has thus far been more powerful than man, who has struggled in vain to subdue this fertile valley to his use.

The winds that pass up the valley of Rio de la Plata to the mountains of Peru, Bolivia, and Argentina are not so heavily charged with moisture as those of the Amazon Valley; consequently the thick forests and dense vegetation gradually disappear, and, instead of an inland sea, there are vast plains or pampas over which roam herds that could not live in the valley of the Amazon. Thus the difference in the rainfall changes the entire vegetal and animal life.

Through the center of South America, from the Caribbean Sea to the straits of Magellan, there is a vast stretch of lowland through which run the waters of the Orinoco, Amazon, and la Plata, with low divides between their valleys. A boat can pass up the Orinoco, thence by Cassiquiare River to the Rio Negro, a branch of the Amazon, thence through the Amazon and its branches to a low divide between the valleys of the Amazon and Rio de la Plata. Here there is a carry of 6 or 8 miles, and then, continuing down la Plata to the Atlantic Ocean, the traveller may make a water journey of over 3,000 miles between the Cordillera and the eastern plains of South America.

The easterly currents flowing from the Antartic pole are deflected by Cape Horn along both the eastern and western coasts of Patagonia. On the eastern coast the winds blow offshore, leaving that coast arid. The westerly current, as it approaches the tropics, is deflected further westward and forms the greatest of the equatorial currents. The moisture of the winds that blow over this Antarctic current is precipitated on the cool shores of Patagonia and lower Chile, and these countries are correspondingly enriched, while the same winds continuing over the heated plains of upper Chile, Peru, and southern Ecuador are rarefied

and take up what little moisture there is in these plains, to be afterward condensed and precipitated on the mountain slopes.

From this cause the western coast of South America for the 3,000 miles from lower Chile to upper Ecuador is dry and barren, and would be uninhabited except for the mines of gold and silver in the mountains and the deposits of nitrates and guano along the coast and on the islands. Yet the rain-fall in South America is greater than in any other part of the world, and more than twice as great as the rain-fall in Asia.

NORTH AMERICA.

The northern equatorial current, less powerful than the southern, crosses the Pacific about the tropic of Cancer, where it is deflected by Japan, and flows northward as the Kuroshiwo current, re-crossing the Pacific in a northeasterly direction.

The Pacific Ocean is so wide that it is doubtful if this current would reach the American coast were it not for the drift caused by the wind which blows across the Pacific with strong and steady force. When it strikes the shores of North America it is feebler and has a lower temperature than the Gulf Stream of the Atlantic Ocean on reaching the coast of Europe.

The currents of wind strike the coast between the fiftieth and fifty-fifth degrees of north latitude, the region of greatest rain-fall, and are in part deflected northward and southward by the coast range of mountains; the remaining portion blows over the mountains and up the valley of the Columbia. Continual fogs and rains abound on these shores, and the coasts of southern Alaska, British Columbia, Washington, and Oregon are covered with the densest and largest growth of evergreen forest in the world. These winds prevail as far southward as the latitude of San Francisco, where the southeasterly trade winds commence and blow offshore, leaving southern California and the western coast of Central America a zone of calms, dry and barren.

While the western coast of the continent is bathed by the waters of the Pacific, its eastern shores are washed by the equatorial current of the northern Atlantic, which flows around the West India Islands, through Caribbean Sea and the Gulf of Mexico. The trade winds from the Gulf of Mexico water the eastern coasts of Central America and Mexico, and impinging on the mountains of the interior are deflected toward the north and east over the Southeastern States and up the Mississippi Valley, where they unite with the warm winds which blow directly up the valley from the Gulf of Mexico, and water the valley of the Mississippi. The rainfall in the upper part of the valley is derived largely from the Rocky Mountains, the waters of the Pacific carried by the winds and deposited on the Rocky Mountains as rain and snow, being again evaporated and carried eastward to fall as rain.

This great valley extends from Canada southward to the Gulf of Mexico, and from the Rocky Mountains eastward to the Alleghanies;

it is 1,500 miles long and about 2,000 miles wide, the largest and richest valley of the temperate zone.

A very low and narrow divide separates the Mississippi Valley from another great valley extending from the Rocky Mountains eastward, with a gentle slope to Hudson Bay and the Atlantic. It is as long from west to east as the valley of the Mississippi is from north to south, and is from 500 to 600 miles wide. The western portion of this plain is drained by Saskatchewan River. The winds which blow over this valley from the Rocky Mountains in some years water imperfectly the western portion of this plain, but with a copious rain-fall the land yields abundantly; the eastern portion is watered from Hudson Bay, lakes Winnipeg, Manitoba, and the other large lakes of that province. As the climate is cold, less rainfall is required than in the valley of the Mississippi.

Another very low divide separates this valley from the great plain, 2,500 miles long, descending with a gentle slope to the Arctic Ocean, through which runs the Mackenzie River. The winds that blow from the Arctic Ocean fall in rain and snow in this valley.

Thus, through the center of America, from the Arctic to the Antartic Oceans, there are no high elevations, while there is a more uniform distribution of rain-fall and temperature than on any other continent.

From the Arctic Ocean cold currents of water flow along both the eastern and western coasts of Greenland and bear immense icebergs and fields of ice southward until they meet the warm waters of the Gulf Stream, when the ice melts, causing fog banks and depositing the débris brought from the Arctic glaciers, thus aiding in the making of the great fishing banks of Newfoundland. The Arctic current, still cold, runs southward inshore from the Gulf Stream, and affects the climate of North America to the latitude of New York if not to Cape Hatteras.

From the Caribbean Sea and the Gulf of Mexico the Gulf Stream passes around Florida and flows along the southern Atlantic States. The currents of air from the Gulf Stream blow over slightly cooler waters and deposit rain on the eastern side of the Alleghanies and water the eastern coast of the United States.

EUROPE.

The main Gulf Stream is deflected, by the shape of the ocean bottom and the contour of North America, northward and eastward toward Europe; but its drift is largely increased by the winds. The drift from the southward sets around the North Cape of Norway, 71° north latitude, keeping the coast free from ice all the year round, and is felt in the Kara Sea. It is by means of this current that Nansen hopes to be borne through the Kara Sea and from the Lena Delta by way of the north pole to Greenland.

The winds that blow over the Gulf Stream water the western coast

of France, Great Britain, and Scandinavia, and temper the climate of these northern regions to such a degree that Stockholm and St. Petersburg have become great cities, while in a lower latitude in Labrador, on the other side of the Atlantic, "The country is so rocky and rough and the temperature so intensely cold in the winter (lower than the inhabited parts of Greenland) that Labrador would be worthless and uninhabitable except for the seals and fish." These currents are deflected by the coasts of France and Spain toward the west and are drifted in different directions by the wind, watering the eastern coasts of Spain and Portugal, but having precipitated their moisture they leave the high lands of Spain dry, cold in winter and hot in summer.

In the Mediterranean the evaporation is much greater than in the Atlantic Ocean; its water is therefore salt and heavier. To supply this loss by evaporation water flows from the Atlantic into the Mediterranean from west to east as a surface current. The projection of Italy and Greece into the sea deflect these currents along each coast of both countries.

The general course of the winds of southern Europe is interrupted by the Alps and Apennines in Italy, and by the high mountains in Greece. Land and sea breezes water these countries in August and September, while the winter snow on the Alps fills the Italian streams in summer and irrigates the land through numerous canals.

A plain, beginning in Holland and Belgium, runs through Germany, gradually growing broader, into Russia, where it is known as the Black zone; thence northeastward through a large part of Siberia. It is low in the west, gradually rising toward the east, though in Siberia its northern margin dips gently beneath the Arctic Ocean. The western part of this plain is watered by the winds from the Atlantic and from the North and Baltic seas and the Gulf of Finland. The eastern part in Siberia is watered by the winds from the Arctic Ocean. These plains are the granary of Europe and Siberia, although a small part, comparatively, of the Siberian plain is good for corn.

ASIA.

The regularity in the motion of the currents of air and water prevailing in the Western Hemisphere and the Atlantic Ocean is apparently lacking in Asia and the Indian Ocean. The mountains of America run northward and southward, and have little, if any, effect in originating currents of air, and none at all on the ocean currents. In Asia the largest and highest mass of mountains in the world runs east and west, and from their foothills the great plains of India and China extend to the Indian Ocean and the China Sea, bringing a polar climate into close contact with the torrid zone.

Cold winter winds blow from the Himalayas and the high plateaus of central Asia southwestward into Indian Ocean and China Sea and drift the waters with them. When the sun turns toward the north in

the summer solstice and the plains in India and China become heated by the torrid sun the wind changes and blows toward the northeast. At the meeting of the winds the monsoon breaks, and the cyclones of India and the typhoons of China follow. They are soon over, and then the monsoon blows over Indian Ocean and China Sea. All India, Kashmir, and western Tibet, Farther India, Annam, and eastern China and Japan are well watered, 50 inches of rain falling in a year in some parts of India.

In these countries there are generally six months of rainy season and six months of dry. In parts of India the water of the rainy season is stored in large reservoirs for irrigation in the dry season, while in China numerous canals between the different rivers in like manner irrigate the land. India and China are among the richest countries of the world and have the densest population, though destined to be surpassed in the future by the population of the Amazon and Mississippi valleys.

We have thus seen the effects of the winds and ocean currents in modifying the climate and in enriching the great valleys of South America and North America, of Europe, India, China, and Japan.

DESERTS OR BASINS.

About one-fifth of the territory in each continent is arid and desert land. With one or two possible exceptions these arid regions are *basins*, where the rivers and rain-fall either run into salt lakes or are lost in the desert and never reach the ocean. These deserts are caused by the winds which blow either from colder over warm areas and are therefore dry, or over vast plains or mountainous regions upon which they have precipitated their moisture.

The average rain fall on the great deserts does not exceed 10 inches a year, and the evaporation is usually greater than the rain-fall. They are situated generally between the twentieth and fortieth degrees of north latitude and between the twentieth and thirtieth degrees of south latitude. In the northern belt are the Carson and other basins of Nevada, the Salt Lake of Utah, the desert of Sahara, Arabia, Persia, the Aral-Caspian desert, the Tanin Gobi and Mongolia desert. In the southern belt is the desert of Atacama in South America, Kalahari in South Africa, and the Australian deserts. These basins in the northern belt contained formerly lakes much greater than are now found in either of the continents.

Salt Lake was formerly much larger and deeper, for its waters once beat upon shores 1,000 feet higher up the mountain sides than at present. Its waters then found their way to the ocean. This was probably in the ice age, when the surrounding mountains were covered with snow and great glaciers, and the evaporation was much less than the rain-fall and the water from the melting glaciers.

In the desert of Sahara numerous dry water-courses show where great rivers formerly ran into Lake Tchad.

In Asia the Caspian and Aral seas were connected, covering a territory many times greater than at present, with an outlet to the Bosphorus and Mediterranean.

We have not sufficient knowledge of Arabia to know the former condition of that arid country. The process of desiccation is still going on, and how much longer it will continue no one can tell.

MOUNTAINS OF AMERICA.

Next we will notice the influence of the mountains on the atmosphere, either in enriching or impoverishing a country, or in intensifying the movements of the currents of air and water.

The mountains of America rise at the Arctic Ocean and from the divide between the Mackenzie and Yukon rivers. A second range runs from northeastern Alaska through Mount St. Elias. Then these two bands extend through British Columbia, gradually widening as new ranges arise until they obtain a width of 500 miles at the boundary line between British Columbia and the United States, and a width of 1,000 miles on the line of the Union Pacific Railroad. These two ranges, the Sierra Nevada and the Rocky mountains, come together in southern Mexico and extend as a single range through Central America and the Isthmus of Panama. On entering South America this range again divides, forming the Cordilleran and the Andes systems, and thence they extend southward, with a varying width between them of from 40 to 200 miles. They are connected from east to west by several cross-ranges or spurs. From southern Chile the Andes continues as one chain through Patagonia and Terra del Fuego to Cape Horn. This is the longest and most persistent chain of mountains in the world. The peaks gradually rise in height from north to south until in Chile, Aconcagua, 22,427 feet in height, is the culminating point; thence southerly the range gradually lowers to an elevation of a few hundred feet only at the Straits of Magellan and Cape Horn. Several volcanoes in this long range rise to a greater elevation than any of the non-volcanic peaks.

In North America the currents of air from the Pacific Ocean, in passing over the Coast, Sierras, and other ranges, deposit a large portion of their moisture on the mountains. Between these ranges are warm valleys, and the winds chilled in crossing the mountains evaporate the little moisture in these valleys, and they are left dry and arid unless irrigated by mountain streams. Thus we have a succession of arid valleys and green mountain ranges moistened with rain and snow, and rich in forests and vegetation. A number of these valleys are inclosed basins, from which the mountain streams have no outlet to the ocean and in some of which saline lakes are found.

MOUNTAINS OF ASIA.

In Asia we have the largest continent, the highest mountains, the most elevated plateaus, and the greatest extent of desert land in the world.

The Pamir, or "roof of the world"—"the abode of the Gods," as it was called by the inhabitants—is a vast plateau of 30,000 square miles area, with a north and south extension of about 400 miles, and with a mean elevation of 12,000 feet. It is traversed by a high range of mountains, culminating in the Taghama, 25,500 feet in height. The Pamir was the only barrier Alexander could not pass. Now, the English, the Russians, and the Chinese meet on this plateau and struggle for the control of Asia. From it branch all the great mountain ranges of Asia.

The Hindu Kush range runs west through Afghanistan, between Persia and Turkestan, along the southern shore of the Caspian Sea, culminating in Mount Ararat, thence as the Caucasus Mountains to the Black Sea, while a spur of this chain follows the southern shores of the Black Sea to the Mediterranean. The Himalayas run a little south of east from the southern part of the Pamir for 1,500 miles, separating India from Tibet and China.

The Kuen Luen range, sometimes considered as an extension of the Hindu Kush, runs from the middle of the Pamir through western and part of central China for 2,700 miles. The Thian Shan runs from the northern end of the Pamir northeast, separating Tarim and Mongolia from Siberia. As it approaches the ocean it turns toward the north and ends in Kamchatka, forming the great divide between the waters of the Arctic and Pacific oceans. Between these mountain ranges are elevated plateaus, and the former dominate the rainfall and temperature of the continent.

The steeper slope of the mountains of Asia is toward the Indian Ocean. Between the Himalayas and Kuen Luen ranges and running from the Pamir east is the highest and longest plateau in the world, varying from 17,000 to 10,000 feet, its lowest elevation.

Above this plain the mountains tower from 4,000 to 18,000 feet. Their summits are covered with everlasting snow from 8,000 to 10,000 feet below their crests. Here is truly the "abode of the snow." This plateau, from its height and position between two ranges of mountains, is cold in winter and hot in summer. This is Tibet, the land of the Llama. Here all the great rivers that empty into the Pacific and Indian oceans, excepting the Yukon, the Columbia, the Colorado, and the Zambesi, have their source.

In the western part of Tibet the Indus and Brahmaputra rise, one running west through a pass 14,000 feet in height into India; the other running east, through passes thus far inaccessible and unknown into India; east of the head waters of these two rivers rise the rivers of Siam and farther India.

Farther to the northeast rise the great rivers of China, the Hoang-ho and Yang-tse-kiang. Their valleys are separated by high chains of mountains, extending in a northwest and southeast direction. The Hoang-ho runs north and east through the temperate zone of China, and the Yang-tse-kiang south and east through the semitropical regions of middle China. As they gradually approach, they inclose a great valley and become the arteries of the superabundant life of the Empire. The eastern part of this great valley, watered by the winds from the China Sea, is crossed from northeast to southwest by parallel ridges, from which numerous streams descend. The valley of eastern China is thus abundantly watered and the rich soil yields bountiful crops. For thousands of years this region has been the home of the Chinese, a self-dependent world. It is a limited territory of 1,300 000 square miles area, no larger than the valley of the Mississippi; yet it sustains a population of 400,000 000 or one-third of the people of the globe.

North of the Kuen Luen Mountains, and the valley of the Hoang-ho and south of the Thian Shan, is the plateau of the Tarim, sometimes called Eastern Turkestan. It is much lower than Tibet, and is traversed by cross-ranges of hills or low mountains, through which flows the river Tarim. Little rain falls on this plateau, the sand from the desert is gradually covering the fertile valleys, the ancient lakes are now little more than salt marshes, and where formerly lived bands of Huns and Vandals that over-ran Europe, now only a few shepherds find a scanty living. This part of the world seems exhausted. "Without a shrub or tree or blade of grass," and no longer fit for the residence of man, it has become the sole home of the wild horse and the yak. East of this plateau of Tarim are the deserts of Gobi and Mongolia, which extend far eastward toward the sea of Japan, a high range of mountains separating Mongolia, however, from the seacoast, so that only dry winds blow over these great deserts.

North of the Thian Shan and the Altai mountains is the great plain of Siberia. It starts from a lower level than that of the Tarim desert and descends with a gradual slope northward for 1,500 miles to the Arctic Ocean. These plains resemble in some respects the great plains of the United States, but the latter slope toward the east and south with a climate growing continually warmer, while the Siberian plains slope toward the north, the temperature growing continually colder. The winds in summer blow from the Arctic Ocean over these plains to the Altai Mountains, while in the winter they blow from the mountains to the ocean. There is a slight evaporation from the Arctic Ocean, but the temperature of Siberia is so low and the summers so short that the plains require comparatively slight rain-fall to fertilize them.

There is a large portion of Asia, Arabia, Persia, Turkestan, including Caspian and Aral seas, to which we have not particularly referred because it is entirely outside of the influence of either the monsoon,

trade, or other moisture-bearing winds. This territory extends from Arabia northeastward beyond the Lake of Balkash into Siberia, a vast extent of country, larger than Europe—a dry, rainless desert, hot in summer and cold in winter. Part of this region is from 6,000 to 7,000 feet above the level of the sea, part below the sea level, yet neither height nor depression makes any difference in this arid land. Formerly sections of these countries were thickly populated. The Aral and Caspian basins were called the "Garden of the world." In Mesopotamia were Ninevah, Bagdad, and Babylon; in Persia, Susa and Persopolis. Historians tell us of great cities, flourishing empires, where now is only a barren and sandy desert. We do not know whether the climate has changed or whether in ancient days the country was thoroughly irrigated, and now through neglect has been buried deep in the sand of the desert. Although four-fifths of Asia are either desert or mountainous land and are only scantily inhabited, two-thirds of the population of the world are found within its borders.

THE ICE AGE AND ITS WORK.*

By A. R. Wallace, F. R. S.

I. ERRATIC BLOCKS AND ICE SHEETS.

It is little more than fifty years ago that one of the most potent agents in modifying the surface features of our country was first recognized. Before 1840,—when Agassiz accompanied Buckland to Scotland, the Lake District, and Wales, discovering everywhere the same indications of the former presence of glaciers as are to be found so abundantly in Switzerland,—no geologist had conceived the possibility of a recent glacial epoch in the temperate portion of the Northern Hemisphere. From that year however a new science came into existence, and it was recognized that only by a careful study of existing glaciers, of the nature of the work they now do, and of the indications of the work they have done in past ages, could we explain many curious phenomena that had hitherto been vaguely regarded as indications of diluvial agency. One of the first fruits of the new science was the conversion of the author of *Reliquiæ Diluvianæ*—Dr. Buckland—who, having studied the work of glaciers in Switzerland in company with Agassiz, became convinced that numerous phenomena he had observed in this country could only be due to the very same causes. In November, 1840, he read a paper before the Geological Society on the "Evidences of glaciers in Scotland and the north of England," and from that time to the present the study of glaciers and of their work has been systematically pursued with a large amount of success. One after another crude theories have been abandoned, facts have steadily accumulated, and their logical though cautious interpretation has led to a considerable body of well-supported inductions on which the new science is becoming firmly established. Some of the most important and far reaching of these inductions are however still denied by writers who have a wide acquaintance with modern glaciers; and as several works have recently appeared on both sides of the controversy, the time seems appropriate for a popular sketch of the progress of the glacial theory, together with a more detailed discussion of some of the most disputed points as to

* Selections from article in *The Fortnightly Review*, November and December, 1893; vol. LIV, pp. 616–634, 749–774.

which it seems to the present writer that sound reasoning is even more required than the further accumulation of facts.*

In the last century Swedenborg, Linnæus, Pallas, De Luc, and many other eminent writers took notice of the remarkable fact that in Scandinavia, Russia, Germany, and Switzerland detached rocks or bowlders were found, often in great abundance and of immense size, and of a kind that did not exist *in situ* in the same district, but which were often only to be discovered in remote localities, sometimes hundreds of miles away. Those who ventured to speculate on the origin of these travelled rocks usually had recourse to water power to account for their removal; and, as their large size and often elevated position required some unusual force to carry them, there arose the idea of enormous floods sweeping over whole continents; and for a long time this diluvial theory was the only one that appeared to be available, although the difficulties of its application to explain all the phenomena became greater the more closely those phenomena were studied. Still, there was apparently no other known or conceivable means of accounting for them, and for the enormous mounds of gravel or clay intermixed with bowlders which often accompanied them; and the efforts of geologists were therefore directed to the discovery of how the water power had acted and by what means the supposed floods could have been produced.

There were not wanting men who saw that no action of water alone could account for the facts. Sir James Hall pointed this out with regard to erratics on the Jura, whose source was undoubtedly in the far distant Alps; and Mr. Grainger, in America, described some of the parallel grooves and flutings running for nearly a mile in Ohio, strongly arguing that no action of running water could have produced them, but that an agent was required, the direction of whose movement was fixed and unalterable for long distances and for a great length of time. No light was however thrown on the problem till 1822, when Venetz, a Swiss engineer, finding that existing glaciers varied in extent from year to year and that historical records showed them to have considerably increased during the last eight centuries, was further led to observe that long before the historical era the glaciers had been immensely more extensive, as shown by the smooth and rounded rocks, by longitudinal scratches and grooves pointing down the valleys, and by numbers of old moraines exactly similar in form and materials to those deposited by existing glaciers. He read a paper before the Helvetic Society of Natural History, and urged that glaciers once stretched

* The works referred to are: *Do Glaciers Excavate?* by Prof. T. G. Bonney, F. R. S. (*The Geographical Journal*, vol. I, No. 6); *The Glacial Nightmare and the Flood*, by Sir H. H. Howorth, M. P., F. R. S.; *Fragments of Earth Lore*, by Prof. James Geikie, F. R. S.; *Man and the Glacial Period*, by Prof. G. F. Wright, F. G. S. A.; *La Période Glaciaire*, by A. Falsan; and the *Glacialists' Magazine*, edited by Percy F. Kendall, F. G. S.; from which works, and from those of Lyell, Ramsay, Geikie, and the American geologists, most of the facts referred to in the present article are derived.

down the Rhone Valley as far as the Jura, and there deposited the erratic blocks which had so puzzled the diluvialists to explain.

Other writers soon followed the clue thus given. In 1835, Charpentier, after a close study of the erratic blocks and of their sources, adopted the views of Venetz. Agassiz followed, and by his strenuous advocacy did much to spread correct views as to the former extension of the Alpine glaciers, and their capability of explaining the numerous superficial phenomena which in all northern countries had been thought to afford proofs of enormous floods and of the submergence of a large part of Europe under a deep sea. He has therefore gained the reputation of being the originator of the modern school of glacialists, which undoubtedly owes much to his energy, research, and powers of exposition, though all the more important facts, as well as the logical conclusions to be drawn from them, had been pointed out by previous writers.

Before proceeding further, it will be well to give a brief outline of the phenomena which led to the conclusion that glaciers have formerly existed in districts and countries where even perpetual snow on the mountain tops is now unknown. These may be briefly classed as (1) moraines and drifts; (2) rounded, smoothed, or planed rocks; (3) striæ, grooves, and furrows on rock-surfaces; (4) erratics and perched blocks.

(1) Moraines are those heaps or ridges of rock and other debris which are deposited on the surface of a glacier from the precipices or mountain slopes which border it, and which form what are termed lateral and medial moraines while upon it, and terminal moraines when, being gradually discharged at its end, either from above or from beneath it, they form great heaps of rock and gravel corresponding in outline and extent to that of the terminal ice cliff. Such moraines can be seen on and near all existing glaciers, and their mode of formation and characteristics are perfectly well known. - - -

(2) Smoothed and rounded rocks, called in Switzerland "roches moutonnees," from their supposed resemblance at a distance to sheep lying down, are perhaps the most general of all the indications of glacial action. Every glacier carries with it, imbedded in its under surface, numbers of rocks and stones, which, during the slow but unceasing motion over its bed, crush and grind down all rocky projections, producing in the end gently rounded or almost flat surfaces even on the hardest and toughest rocks. In many of the valleys of Wales, the Lake District, and Scotland every exposed rock has acquired this characteristic outline, and the same feature can be traced on all the rocky slopes and often on the summits of the lesser heights; and the explanation of how these forms have been produced is not a theory only, but has been observed in actual operation in the accessible portions of many glaciers. Rocks and stones are to be seen embedded in the ice and actually scratching, grooving, and grinding the rock beneath in their slow but irresistible onward motion. - - -

On the whole, considering their abundance in all glaciated regions and the amount of information they give as to the direction and grinding power of ice, these rounded rocks afford one of the most instructive indications of the former presence of glaciers; and we must also agree with the conclusion of Darwin (in a paper written after studying the phenomena of ice-action in North Wales, and while fresh from his observation of glaciers and icebergs in the Southern Hemisphere) that "one of the best criterions between the effects produced by the passage of glaciers and of icebergs is boss or dome-shaped rocks."

(3) Striated, grooved, and fluted rocks, though closely connected with the preceding, form a distinct kind of evidence of the greatest value. Most of the bosses of rock just described have been exposed to the action of the atmosphere, perhaps since the ice left them, and have thus become more or less roughened or even disintegrated; but where the rocks have been protected by a covering of drift, or even of turf, and have been recently exposed, they often exhibit numerous parallel striæ, varying from the finest scratches to deep furrows a foot or more in diameter. - - - Perhaps none of the effects of ice so clearly demonstrate the action of glaciers as opposed to that of icebergs, owing to the general constancy of the direction of the striæ, and the long distances they may be traced up and down slopes, with a steadiness of motion and evenness of cutting power which no floating mass could possibly exert. - - -

(4) Erratic blocks were among the phenomena that first attracted the attention of men of science. Large masses of granite and hard metamorphic rock, which can be traced to Scandinavia, are found scattered over the plains of Denmark, Prussia, and northern Germany, where they rest either on drift or on quite different formations of the Secondary or Tertiary periods. One of these blocks, estimated at 1,500 tons' weight, lay in a marshy plain near St. Petersburg, and a portion of it was used for the pedestal of the statue of Peter the Great. In parts of north Germany they are so abundant as to hide the surface of the ground, being piled up in irregular masses forming hills of granite bowlders, which are often covered with forests of pine, birch, and juniper. Far south, at Fürstenwalde southeast of Berlin, there was a huge block of Swedish red granite, from one-half of which the gigantic basinwas wrought which stands before the New Museum in that city. - - -

It is however in Switzerland that we find erratic blocks which furnish us with the most conclusive testimony to the former enormous extension of glaciers; and as these have been examined with the greatest care, and the facts, as well as the main inductions from the facts, are generally admitted by all modern writers, it will be well to consider them somewhat in detail. It will be found that they give us most valuable information both as to the depth and extension of ancient glaciers, and also as to the possibilities of motion in extensive ice-sheets.

The most important of these facts relate to the erratic blocks from the higher Alps, which are found on the flanks of the Jura Mountains wholly formed of limestone, on which it is therefore easy to recognize the granites, slates, and metamorphic rocks of the Alpine chain. These erratic blocks extend along the Jura range for a distance of 100 miles, and up to a height of 2,015 feet above the Lake of Neufchatel. The first important point to notice is that this highest elevation is attained at a spot exactly opposite, and in the same direction as, the Rhone Valley, between Martigny and the head of the Lake of Geneva, while north or south of this point they gradually decline in elevation to about 500 feet above the lake. The blocks at the highest elevation and central point can be traced to the eastern shoulder of Mont Blanc. All those to the southwest come from the left-hand side of the Lower Rhone Valley, while those to the northeast are all from the left side of the Upper Rhone Valley and its tributaries. Other rocks coming from right-hand side of the Upper Rhone Valley are found on the right-hand or Bernese side of the great valley between the Jura and the Bernese Alps.*

Now, this peculiar and definite distribution, which has been worked out with the greatest care by numerous Swiss geologists, is a necessary consequence of well-known laws of glacier motion. The débris from the two sides of the main valley form lateral moraines which, however much the glacier may afterwards be contracted or spread out, keep their relative position unchanged. Each important tributary glacier brings in other lateral moraines, and thus when the combined glacier ultimately spreads out in a great lowland valley the several moraines will also spread out, while keeping their relative position, and never crossing over to mingle with each other. So soon as this definite position of the erratics was worked out it became evident that the first explanation—of a great submergence, during which the lower Swiss valleys were arms of the sea and the Rhone glacier broke off in icebergs, which carried the erratics across to the Jura—was altogether untenable, and that the original explanation of Venetz and Charpentier was the true one. - - -

We must now consider briefly the distribution of erratics in North America, because they present some peculiar features and teach us much concerning the possibilities of glacier motion.

An immense area of the Northeastern States, extending south to New York, and then westward in an irregular line to Cincinnati and St. Louis, is almost wholly covered with a deposit of drift material, in which rocks of various sizes are embedded, while other rocks, often of enormous size, lie upon the surface. These blocks have been carefully studied by the American geologists, and they present us with some very interesting facts. Not only are the distances from which they have been transported very great, but in very many cases they are found at

* A map showing the lines of dispersal of these erratics is given in Lyell's *Antiquity of Men*, p. 344, and is reproduced in my *Island Life*, p. 111.

a greater elevation than the place from which they must have come. Prof. G. F. Wright found an enormous accumulation of bowlders on a sandstone plateau in Monroe County, Pa. Many of these bowlders were granite, and must have come either from the Adirondack Mountains, 200 miles to the north, or from the Canadian Highlands, still farther away. This accumulation of bowlders was 70 or 80 feet high, and it extended many miles, descending into a deep valley 1,000 feet below the plateau in a nearly continuous line, forming part of the southern moraine of the great American ice sheet.

On the Kentucky hills, about 12 miles south of Cincinnati, conglomerate bowlders containing pebbles of red jasper can be traced to a limited outcrop of the same rock in Canada to the north of Lake Huron, more than 600 miles distant, and similar bowlders have been found at intervals over the whole intervening country. In both these cases the blocks must have passed over intervening valleys and hills, the latter as high or nearly as high as the source from whence the rocks were derived. Even more remarkable are numerous bowlders of Helderberg limestone on the summit of the Blue Ridge, in Pennsylvania, which must have been brought from ledges at least 500 feet lower than the places upon which they now lie. The Blue Ridge itself shows remarkable signs of glacial abrasion, in a well-defined shoulder marking the southern limit of the ice (as indicated also by heaps of drift and erratics), so that Mr. Wright concludes that several hundred feet of the ridge have been worn away by the ice.

The crowning example of bowlder transportation is however afforded by the blocks of light-gray gneiss discovered by Prof. Hitchcock on the summit of Mount Washington, over 6,000 feet above sea level, and identified with Bethlehem gneiss, whose nearest outcrop is in Jefferson, several miles to the northwest, and 3,000 or 4,000 feet lower than Mount Washington.

These varied phenomena of erratic blocks and rock striations, together with the enormous quantity of bowlder clay and glacial drift spread over the whole of the Eastern States, terminating southward in a more or less abrupt line of mounds having all the characteristics of an enormous moraine, have led American geologists to certain definite conclusions in which they all practically agree. It may be well first to give a notion of the enormous amount of the glacial débris under which a large part of the Eastern States is buried. In New England these deposits are of less thickness than farther south, averaging from 10 to 20 feet over the whole area. In Pennsylvania and New York, east of the Alleghanies, the deposits are very irregular, often 60 or 70 feet thick and sometimes more. West of the Alleghanies, in New York, Pennsylvania, and Ohio, the thickness is much greater, being often 150 or 200 feet in the wide valleys and 40 or 50 feet on many of the uplands. Prof. Newberry calculates that in Ohio it averages 60 feet deep over an area of 25,000 square miles.

The direction of the striæ and of the travelled bowlders, together with the form of the great terminal moraines, show that there must have been two main centers of outflow for the ice sheet, one over Labrador, the other over the Laurentian Highlands north of Lake Superior. The southern margin of the drift may be roughly represented by portions of circles drawn from these two points as centers. The erratics on the summit of Mount Washington show that the ice sheet must have been a mile thick in its neighborhood, and much thicker at the centers of dispersion, while the masses of drift and erratics on plateaus 2,000 feet high near its southern boundary indicate a great thickness at the termination. The Laurentian plateau is now about 2,000 feet above the sea level, but there are numerous indications from buried river channels, filled with drift and far below the sea, which lead to the conclusion that during the Ice Age the land was much higher. That snow can accumulate to an enormous extent over land of moderate height when the conditions are favorable for such an accumulation is shown by the case of Greenland, the greater part of whose surface is a vast plateau of ice flowing outward by numerous glaciers into the sea. The center of this plateau where Dr. Nansen crossed it was over 9,000 feet above sea-level, and it may be very much higher farther north. It therefore seems probable that the great American ice sheet was at least as high, and perhaps much higher, and this would give sufficient slope for the flow to the southern border. Of course, during the successive stages of the glaciation there may have been numerous local centers from which glaciers radiated, and during the passing away of the Ice Age these local glaciers would have left striæ and other indications of their presence. But so much of the area covered by the drift—all in fact south of the New England mountains and the Great Lakes—is undulating ground, hill, valley, and plateau of moderate height; that here all the phenomena seem to be due to the great confluent ice sheet during the various phases of its advance and its passing away. - - -

It will now be well briefly to sketch the distribution of erratic blocks in Great Britain, and the conclusions to be drawn from them as to the former existence of an ice sheet under which the greater part of our islands was buried.

Every mountain group north of the Bristol Channel was a center from which, in the earlier and later phases of the Ice Age, glaciers radiated; but many facts prove that during its maximum development these separate glacier systems became confluent, and formed extensive ice sheets, which overflowed into the Atlantic Ocean on the west and spread far over the English lowlands on the east and south. This is indicated partly by the great height at which glacial striæ are found, reaching to 2,500 feet in the lake district and in Ireland, somewhat higher in North Wales, and in Scotland to nearly 3,500 feet; but also by the extraordinary distribution of erratic blocks, many of which can be traced to locali-

ties whence they could only have been brought across the sea. The direction of the glacial striæ and of the smoothed side of ice-worn rocks also indicate that the shallow seas were all filled up by ice. - - On all sides of Ireland, except the southern coast, the ice flowed outward, but on the northeast the flow was diverted southward, and on the extreme north, westward, by the pressure of the overflowing ice sheet of Scotland which here encountered it. In like manner, the ice marks on the east coast of Ireland and the west coast of Wales are diverted southward by the mutual pressure of their ice sheets, which, together with that of the west of Scotland, filled up St. George's Channel. That such was the case is further proved by the fact that the Isle of Man is ice-bound in a general direction from north to south, and to the summit of its loftiest mountains, which rise to a height of over 2,000 feet. This could only have been done by an ice sheet flowing over it, and this view is further supported by some most remarkable facts in the dispersal of local erratics. These are always found to the south of the places where they occur in situ, never to the north; and, what is still more noteworthy, they are often found far above the native rock. Thus bowlders of the peculiar Foxdale granite are found about 1,400 feet higher than the highest point where there is an outcrop of this rock.

The Scotch ice sheet flowed outward on all sides, but on the east it was met by the southward extension of the great Scandinavian ice sheet. On the extreme north the meeting of these two ice sheets resulted in a flow to the northwest which glaciated the Orkney Islands, while the Shetlands, much farther north, received the full impact of the Scandinavian ice alone, and are therefore glaciated from the northeast. The dividing line of the Scotch and Scandinavian ice sheets was in the North Sea, not far from the east coast of Scotland; but farther south, at Flamborough Head and Holderness, the latter impinged on our coast, bringing with it enormous quantities of Scandinavian rocks. Many years ago Prof. Sedgwick described the cliffs of bowlder clay at Holderness as containing "an incredible number of smooth round blocks of granite, gneiss, greenstone, mica slate, etc., resembling none of the rocks of England, but resembling specimens derived from various parts of the great Scandinavian chain." These are mixed however with a number of British rocks from the north and west, indicating the meeting ground of the two conflicting ice sheets. Similar blocks occur all along the coast as far as the cliffs of Cromer in Norfolk. Across the peninsula of Flamborough about 2 miles west of the lighthouse there is a moraine ridge containing a few Scandinavian bowlders, but mainly composed of British rocks. These latter consist of numerous carboniferous rocks from the north and northwest, together with many of Shap granite—a peculiar rock found only on Shap Fell, in the eastern side of the Lake District, together with a few of Galloway granite. These facts, it will be seen, add further confirmation to the theory of great confluent ice sheets indicated by the ice-markings upon

the various groups of mountains, while it is hopelessly impossible to explain them on any theory of local glaciers, even with the aid of submergence and of floating ice. - - -

The center of the great glacier sheet of North Wales appears to have been over the Arenig Mountains, whence erratics of a peculiar volcanic rock have been traced to the north and east, mingling with the last-described group; while a distinct train of these Welsh erratics stretches southeastward to the country west of Birmingham.

In the Isle of Man are found many erratics from Galloway and a few from the Lake District. But the most remarkable are those of a very peculiar rock found only on Ailsa Craig, a small island in the Frith of Clyde, and a single bowlder of a peculiar pitchstone found only in the Isle of Arran. The Ailsa Craig rock has also been found at Moel Tryfaen, on the west side of Snowdon, and more recently at Killiney County, Dublin, on the seashore.*

The case of the bowlders in the Isle of Man, which have been carried nearly 800 feet above their source, has already been mentioned, but there are many other examples of this phenomenon in our islands; and as they are of great importance in regard to the general theory of glacial motion, a few of them may be noted here. So early as 1818 Mr. Weaver described a granite block on the top of Cronebane, a slate hill in Ireland, and several hundred feet higher than any place where similar granite was to be found *in situ;* and he also noticed several deposits of limestone gravel in places from 300 to 400 feet higher than the beds of limestone rock, which are from 2 to 10 miles off. Débris of red sandstone is also found much higher than the parent rock. Bowlders of Shap granite, Mr. Kendal tells us, have passed over Stainmoor by tens of thousands, and in doing so have been carried about 200 feet above their source; and the curious Permian rock, "Brockram," has been carried in the same direction no less than 1,000 feet higher than its highest point of origin.† In Scandinavia there are still more striking examples, erratic blocks having been found at an elevation of 4,500 feet, which could not possibly have come from any place higher than 1,800 feet.‡ We thus find clear and absolute demonstration of glacier ice moving uphill and dragging with it rocks from lower levels to elevations varying from 200 to 2,700 feet above their origin. In Switzerland we have proof of the same general fact in the terminal moraine of the northern branch of the Rhone glacier being about 200 feet higher than the Lake of Geneva, with very much higher intervening ground. - - -

The facts thus established render it more easy for us to accept one of the latest conclusions of British glacialists. A great submergence of a large portion of the British Isles during the glacial period, or in the interval between successive phases of the glacial period, has long

* *Nature,* March 16, 1893; vol. XLVII, p. 464.

† Wright's *Man and the Glacial Period,* p. 154.

‡ James Geikie's *Great Ice Age,* 2d ed., p. 404.

been accepted by geologists, and maps have been often published showing the small group of islands to which our country was then reduced, the supposed subsidence being about 1,400 feet. The evidence for this is the occurrence at a few spots of glacial gravels containing marine shells in tolerable abundance, the most celebrated being at Moel Tryfaen, on the west side of Snowdon, at a height of more than 1,300 feet. Shell-bearing drifts have also been found near Macclesfield at a height of over 1,100 feet, and to the east of Manchester at between 500 and 600 feet elevation. Others have since been found on Gloppa, a hill near Oswestry. The fact that the shell-bearing gravels of Moel Tryfaen are nearly 40 feet thick shows that, if they are due to submergence, the land must have remained stationary at that level for a considerable period of time, and there would probably be other stationary periods at lower levels. Yet nowhere in the valleys or on the hill slopes of Wales, or the Lake District, or in the English lowlands are there any of the old beaches or sea cliffs, or marine deposits of any kind, that must have been formed during such a subsidence and which can hardly have been everywhere cleared away by subsequent glaciation. Another difficulty is that the shells of these drifts are such as could not have lived together on one spot, some being northern species, others southern, some frequenting sandy, others muddy bottoms, some which live only below tidal water, while others are shore species. And, lastly, they are very fragmentary, only a small percentage of entire shells being found. - - -

II. EROSION OF LAKE BASINS.

Lakes are distributed very unequally over the various parts of the world, and they also differ much in their position in relation to other physical peculiarities of the surface. Most of the great continents have a considerable number of lakes, many of great size, situated on plateaus or in central basins; while the northern parts of Europe and North America are thickly strewn with lakes of various dimensions, some on the plains, others in sub alpine valleys, others again high up among the mountains, these latter being of small size and usually called tarns. The three classes of lakes last mentioned occur in the greatest profusion in glaciated districts, while they are almost absent elsewhere; and it was this peculiarity of general distribution, together with the observation that all the valley lakes of Switzerland and of our own country occurred in the track of the old glaciers, and in situations where the erosive power of the ice would tend to form rock-closed basins, that appears to have led the late Sir Andrew Ramsay to formulate his theory of ice erosion to explain them. He was further greatly influenced by the extreme difficulty or complete inadequacy of any possible alternative theory,—a difficulty which we shall see remains as great now as at the time he wrote.

This question of the origin of the lake basins of the glaciated regions

is especially interesting on account of the extreme divergence of opinion that still prevails on the subject. While the general facts of glaciation, the extent and thickness of the old glaciers and ice-sheets, and the work they did in distributing huge erratics many hundred miles from their sources and in covering thousands of square miles of country with thick layers of bowlder clay and drift, are all admitted as beyond dispute, geologists are still divided into two hostile camps when the origin of lake basins is concerned; and the opposing forces seem to be approximately equal. Having for many years given much attention to this problem, which has had for me a kind of fascination, I am convinced that the evidence in favor of glaciation has not been set forth in all its cumulative force, while many of the arguments against it seem to me to be either illogical or beside the point at issue. I have also to adduce certain considerations which have hitherto been overlooked, but which appear to me to afford very strong if not conclusive evidence for erosion as against any alternative theory yet proposed. I shall therefore first set forth, as fully as the space at my command will allow, the general evidence in favor of the ice origin of certain classes of lakes, and the special conditions requisite for the production of lakes by this agency. The objections of the best authorities will then be considered and replied to, and the extreme difficulties of the alternative theories will be pointed out. I shall then describe certain peculiarities, hitherto unnoticed, which clearly point to erosion, as opposed to any form of subsidence and upheaval, in the formation of the lakes in question. Lastly, the special case of the Lake of Geneva will be discussed as affording a battle-ground that will be admitted to be highly favorable to the anti-glacialists, since most of them have adduced it as being entirely beyond the powers of the ancient glaciers to have produced.

1. *The different kinds of lakes and their distribution.*—To clear the ground at the outset, it may be well to state that the great plateau lakes of various parts of the world have no doubt been formed by some kind of earth movements occurring subsequent to the upheaval and partial denudation of the country. It is universally admitted that existing lakes can not be very ancient, geologically speaking, since they would inevitably be filled up by the sediment carried into them by the streams and by the wind. Our lakes must therefore be quite modern features of the earth's surface. A considerable proportion of these plateau lakes are in regions of little rain-fall, and many of them have no outlet. The latter circumstance is a consequence of the former, since it indicates that evaporation balances the inflow. This would have favored the formation of such lakes, since it would have prevented the overflow of the water from the slight hollow first formed, and the cutting of an outlet gorge which would empty the incipient lake. Capt. Dutton, in his account of the geology of the Grand Canyon district, lays stress on this fact, "that the elevation of

a platform across the track of a river rarely diverts it from its course, for the stream saws its bed into the rocks as fast as the obstacle rises." Scanty rain-fall and great evaporation seem therefore to be almost essential to the formation of the larger plateau lakes. Rarely, such lakes may have been formed in comparatively well-watered districts, but the earth movements must in these cases have been exceptionally rapid and extensive, and they are accordingly found most often in countries subject to volcanic disturbances. Such are the lakes of southern Italy, of Macedonia, of Asia Minor, and perhaps those of central Africa.

Quite distinct from these are the sub-alpine lakes of those mountain groups which have been subject to extreme glaciation. These are characteristically valley lakes, occurring in the lower portions of the valleys which have been the beds of enormous glaciers, their frequency, their size, and their depth bearing some relation to the form and slope of the valleys and the intensity of the glaciation to which they have been subject. In our own country we have in Wales a small number of valley lakes; in the lake district, where the ice sheet can be proved to have been much thicker and to have lasted longer, we have more numerous, larger, and deeper lakes; and in Scotland, still more severely glaciated, the lakes are yet more numerous, many of those in the west opening out to the sea and forming the lochs and sounds of the western highlands. Coming to Switzerland, which, as we have seen, bears indications of glaciation on a most gigantic scale, we find a grand series of valley lakes both on the north and south, situated for the most part in the tracks of those enormous glaciers whose former existence and great development is clearly proved by the vast moraines of northern Italy and the travelled blocks of Switzerland and France. In Scandinavia, where the ice age reigned longest and with greatest power, lakes abound in almost all the valleys of the eastern slope, while on the west the fiords or submerged lakes are equally characteristic.

In North America, to the south of the St. Lawrence River and of lakes Ontario and Erie, there are numbers of true valley lakes, as there are also in Canada, besides innumerable others scattered over the open country, especially in the North, where the ice sheet must have been thickest and have lingered longest. And in the southern hemisphere we have, in New Zealand, a reproduction of these phenomena—a grand mountain range with existing glaciers, indications that these glaciers were recently much more extensive, a series of fine valley lakes forming a true lake district, rivaling that of Switzerland in extent and beauty, with fiords on the southwest coast comparable with those of Norway.

Besides these valley lakes there are two other kinds of lakes always found in strongly glaciated regions. These are alpine tarns—small lakes occurring at high elevations and very often at the heads of valleys

under lofty precipices; and small or large plateau or low level lakes which occur literally by thousands in northern Canada, in Sweden, Finland, Lapland, and northwestern Russia. The valley lakes and the alpine tarns are admitted by all geologists to be mostly true rock basins, while the plateau and low country lakes are many of them hollows in the drift with which much of the country is covered, though rock basins are also not unfrequent.

Here then we see a remarkable association of lakes of various kinds with highly glaciated regions. The question is whether there is any relation of cause and effect in the association; and to determine this we must take a rapid survey of other mountain regions where indications of ice action are comparatively slight or altogether wanting, and see whether similar lakes occur there also. The comparison will, I think, prove very instructive.

Spain and Portugal are preeminently mountainous countries, there being a succession of distinct ranges and isolated mountain groups from east to west and from north to south; yet there is not a single valley lake in the whole peninsula, and but very few mountain tarns. Sardinia and Corsica are wholly mountainous, but they do not appear to possess a single valley lake. Nor does the whole range of the Appenines, though there are many large plateau lakes in southern Italy. Farther south we have the lofty Atlas Mountain, but giving rise to no subalpine valley lakes. The innumerable mountains and valleys of Asia Minor have no lakes but those of the plateaus; neither has the grand range of the Lebanon, 100 miles long, and giving rise to an abundance of rivers. Turning to the peninsula of India we have the ranges of the Ghauts, 800 miles long, the mountain mass of the Neilgherries and that of Ceylon, all without such lakes as we are seeking, though Ceylon has a few plateau lakes in the north. The same phenomenon meets us in South Africa and Madagascar—abundance of mountains and rivers, but no valley lakes. In Australia, again, the whole great range of mountains from the uplands of Victoria, through New South Wales and Queensland to the peninsula of Cape York, has not a single true valley lake. Turning now to the New World, we find no valley lakes in the southern Alleghanies, while the grand mountains of Mexico and Central America have a few plateau lakes, but none of the class we are seeking. The extremely mountainous islands of the West Indies—Cuba, Hayti, and Jamaica—are equally deficient. In South America we have on the east the two great mountain systems of Guiana and Brazil, furrowed with valleys and rich in mountain streams, but none of these are adorned with lakes. And, lastly, the grand ranges of the equatorial Andes, for 10 degrees on each side of the Equator, produce only a few small lakes on the high plateaus, and a few in the great lowland river plains—probably the sites of old river channels—but no valley lakes in any way comparable with those of Switzerland or even of our own insignificant mountains. - - -

2. *The conditions that favor the production of lakes by ice erosion.*—Those who oppose the production of lake basins by ice erosion often argue as if the size of the glacier was the only factor, and urge that because there are no lake basins in one valley where large glaciers have been at work, those which exist in another valley where the glaciers were no larger, could not have been produced by them. But this by no means follows, because the production of a lake basin depends on a combination of favorable conditions. In the first place it is evident that ice erosion to some extent must have taken place along the whole length of the glacier's course, and that in many cases the result might be simply to deepen the valley all along, not quite equally, perhaps, but with no such extreme differences as to produce a lake basin. This would especially be the case if a valley had a considerable downward slope, and was not very unequal in width or in the nature of the rocks forming its floor. The first essential to lake erosion is, therefore, a differential action, caused locally either by increased thickness of the ice, a more open and level valley floor, or a more easily eroded rock, or by any combination of these. - - -

It must always be remembered that glacial erosion is produced by the tremendous vertical pressure of the ice, by its lower strata being thickly loaded with hard rocks frozen into its mass, and by its slow but continuous motion. In the lower part of its course a glacier would be most charged with rocky débris in its under strata, since not only would it have been continually breaking off and absorbing, as it were, fresh material during every mile of its onward course, but more and more of its superficial moraines would be engulfed by crevasses or *moulins*, and be added to the grinding material below. That this was so is proved by the great quantity of stones and grit in the "till," which is thought by Prof. James Geikie to consist, on the average, of as much stony matter as clay, sometimes one material preponderating, sometimes the other. The same thing is indicated by the enormous amount of débris often found on the lower parts of large glaciers. The end of the great Tasman glacier in New Zealand is thus completely hidden for 5 miles, and most of the other glaciers descending from Mount Cook have their extremities similarly buried in débris. Dr. Diener found the Milam glacier in the Central Himalayas completely covered with moraine rubbish; and Mr. W. M. Conway states that the lowest 20 miles of the Hispar glacier (40 miles long) are "entirely covered with a mantle of moraine." If these glaciers extended to over 100 miles long, as did the Rhone glacier when it reached the lake of Geneva, much of this débris would probably have found its way to the bottom, and thus supply the necessary grinding material and the abundant stones of the "till" found everywhere in the tracks of the old glaciers.

Again, although ice is viscous and can slowly change its shape to almost any extent, yet it takes a considerable time to adapt itself to

continually changing outlines of the valley bottom. Hence, where great inequalities occur portions of the rocky floor might be bridged over for a considerable space, and where a valley had a narrow V-shaped bottom the sub-glacial stream might eat away so much of the ice that the glacier might rest wholly on the lateral slopes, and hardly touch the bottom at all. On a tolerably wide and level valley bottom, however, the ice would press with its fullest intensity, and its armature of densely packed stones and rock fragments would groove and grind the rocky floor over every foot of its surface, and with a rate of motion perhaps greater than that of the existing Greenland and Alaskan glaciers, owing to the more southern latitude and therefore higher mean temperature of the soil and the ice. At the same time sub-glacial streams, forced onward under great hydrostatic pressure, would insinuate themselves into every vacant groove and furrow as each graving tool successively passed on and the one behind it took a slightly different position: and thus the glacial mud, the product of the erosion, would be continually washed away, finally escaping at the lower extremity of the glacier, or in some cases getting embayed in rocky hollows where it might remain permanently as masses of clayey "till," packed with stones and compressed by the weight of the ice to the hardness of rock itself. The continual lubrication of the whole valley floor by water forced onward under pressure, together with the ever changing form of the under surface of the glacier as it slowly molded itself to the varying contours of the rocks beneath, would greatly facilitate the onward motion. Owing to these changes of form and the great upward pressure of the water in all the hollows to which it gained access, it seems probable that at any one time not more than half the entire bottom surface of the glacier would be in actual contact with the rock, thus greatly reducing the friction; while, as the process of erosion went on, the rock surfaces would become continually smoother and the inequalities less pronounced, so that even when a rock basin had been ground out to a considerable depth the onward motion might be almost as great as at the beginning of the process. - - -

3. *Objections of modern writers considered.*—Prof. Bonney and many other writers ask why lakes are so few, though all the chief valleys of the Alps were filled with ice; and why, for instance, there is no great lake in the Dora Baltea Valley whose glacier produced the great moraines of Ivrea opposite its outlet into the plains of Italy, and which form a chain of hills 15 miles long and 1,500 feet high? The answer, in the case of the Dora Baltea, is not difficult, since it almost certainly has had a series of lake basins at Aosta, Verrex, and other places where the broad level valley is now filled with alluvial gravel. But the more important point is the extreme narrowness of the lower part of the valley above Donnas and again near its entrance into the valley of the Po. The effect of this would be that the great glacier, probably 2,000 feet thick or more, would move rapidly in its upper layers, carrying out

its load of stones and debris to form the terminal moraine, while the lower strata choked in the defiles, would move very slowly. And once out in the open valley of the Po, then a great inlet of the warm Mediterranean Sea, the ice would rapidly melt away in the water and in the warm moist atmosphere, and therefore have no tendency to erode a lake basin. - - -

4. *The alternative theory and its difficulties.*—There is really only one alternative theory to that of ice erosion for the origin of the class of lakes we have been discussing, viz. that they were formed before the glacial epoch, by earth movements of the same nature as those which are concerned in mountain formation; that is, by lateral pressure causing folds or flexures of the surface, and where such flexures occurred across a valley a lake would be the result. - - -

As this theory is put forward with so much confidence, and by geologists of such high reputation, I feel bound to devote some space to its consideration, and shall, I think, be able to show that it breaks down on close examination.

In the first place, it does not attempt to explain that wonderful absence of valley lakes from all the mountain regions of the world except those which have been highly glaciated. It is no doubt true that during the time the lakes were filled with ice instead of water they would be preserved from filling up by the influx of sediment; and this may be fairly claimed as a reason why lakes of this class should be somewhat more numerous in glaciated regions, but it does not in any way explain their total absence elsewhere. We are asked to believe that in the period immediately preceding the glacial epoch—say, in the newer Pliocene period,—earth-movements of a nature to produce deep lakes occurred in every mountain range without exception that was about to be subject to severe glaciation, and not only so, but occurred on both sides of each range, as in the Alps, or all round a mountain range, as in our lake district, or in every part of a complex mountain region, as in Scotland from the Frith of Clyde to the extreme north coast—all in this very limited period of geological time. We are further asked to believe that during the whole period, from the commencement of the ice age to our day, such earth-movements have never produced a single group of valley lakes in any one of the countless mountain ranges and hilly regions throughout the whole of the very much more extensive nonglaciated regions of the globe. This appears to me to be simply incredible. The only way to get over the difficulty is to suppose that earth-movements of this nature occurred only at that one period, just before the ice age came on, and that the lakes produced by them in all other regions have since been filled up. But is there any evidence of this? And is it probable that *all* lakes so produced in non-glaciated regions, however large and deep they might be, and however little sediment was carried down by their inflowing streams, should yet all have disappeared. The theory of the preglacial origin of these lakes thus

rests upon a series of highly improbable suppositions entirely unsupported by any appeal to facts. There is however another difficulty which is perhaps even greater than those just considered. Whatever may be the causes of the compression, elevation, folding, and other earth movements which have led to the formation of mountain masses, there can be no doubt that they have operated with extreme slowness; and all the evidence we have of surface movements now going on show that they are so slow as to be detected only by careful and long-continued observations. On the other hand, the action of rivers in cutting down rocky barriers is comparatively rapid, especially when, as in all mountainous countries, they carry in their waters large quantities of sediment, and during floods bring down also abundance of sand, gravel, and large stones. - - -

It is in fact only on account of this powerful agency that we do not find valley lakes abounding in every mountainous country, since it is quite certain that earth-movements of various kinds must have been continually taking place. But if rivers have always been able to keep their channels clear, during such movements, among the mountains of the tropics and of all warm countries, some reason must be found for their inability to do so in the Alps and in Scotland, in Cumberland, Wales, and southern New Zealand; and as no reason is alleged, or any proof offered, that sufficiently rapid and extensive earth-movements actually did occur in the sub-alpine valleys of these countries, we must decline to accept such a hypothetical and unsatisfactory explanation. - - -

5. *The contours and outlines of the lakes indicate erosion rather than submergence.*—While collecting facts for the present articles it occurred to me that the rival theories of lake formation—erosion and submergence—were so different in their mode of action that they ought to produce some marked difference in the result. There must be some criteria by which to distinguish the two modes of origin. Under any system of earth-movements a valley bottom will simply become submerged, and be hardly more altered than if it had been converted into a lake by building an artificial dam in a convenient situation. We should find therefore merely a submerged valley with all its usual peculiarities. If however the lake basin has been formed by glacial erosion, then some of the special valley features will have been destroyed, and we shall have a distinct set of characters which will be tolerably constant in all lakes so formed. Now I find that there are three such criteria by which we ought to be able to distinguish the two classes of lakes, and the application of these tests serves to show that most of the valley lakes of glaciated countries were not formed by submergence.

The first point is that valleys in mountainous countries often have the river channel forming a ravine for a few miles, afterward opening out into a flat valley, and then again closing, while at an elevation of a hundred or a few hundred feet, at the level of the top of the ravine,

the valley walls sloped back on each side, perhaps to be again flanked by precipices. Now, if such a valley were converted into a deep lake by any form of subsidence, these ravines would remain under water and form submerged river channels. But neither in the lakes, which have been surveyed by the Swiss Government, nor in the Atlas des Lacs Francaises of M. Delebecque, nor in those of the German Alps by Dr. Alois Geistbeck, nor in the lakes of our own country, can I find any indications of such submerged river channels or ravines, or any other of the varied rock features that so often occur in valleys. Almost all these lakes present rather steeply sloping sides with broad, rounded, or nearly level bottoms of saucer shape, such as are certainly not characteristic of sub-aerial valley bottoms, but which are exactly what we might expect as the ultimate result of thousands of years of incessant ice grinding. The point is, not that the lake bottoms may not in a few cases represent the contours of a valley, but that they never present peculiarities of contour which are not unfrequent in mountain valleys, and never show submerged ravines or those jutting rocky promontories which are so common a feature in hilly districts.

The next point is, that alpine lake bottoms, whether large or small, frequently consist of two or more distinct basins, a feature which could not occur in lakes due to submergence unless there were two or more points of flexure for each depression, a thing highly improbable even in the larger lakes and almost impossible in the smaller. Flexures of almost any degree of curvature are no doubt found in the rocks forming mountain chains; but these flexures have been produced deep down under enormous pressure of overlying strata, whereas the surface beds which are supposed to have been moved to cause lakes are free to take any upward or downward curves, and as the source of motion is certainly deep-seated those curves will usually be of very gradual curvature. Yet in the small lake of Annecy there are two separate basins; in Lake Bourget also two; in the small lake of Aiguebellette, in Savoy, there are three distinct basins of very different depths; and in the Lac de St. Point, about 4 miles long, there are also three separate flat basins. In Switzerland the same phenomenon is often found.

The exceedingly irregular Lake of Lucerne, formed by the confluence of many valleys meeting at various angles hemmed in by precipitous mountains, has eight distinct basins, mostly separated by shallows at the narrow openings between opposing mountain ridges. This is exactly what would result from glacier action, the grinding power of which must always be at a maximum in the wider parts of valleys, where the weight of the ice could exert its full force and the motion be least impeded. On the subsidence or curvature theory, however, there is no reason why the greatest depth should occur in one part rather than in another, while separate basins in the variously diverging arms of one lake seem most improbable. - - -

The third point of difference between lakes of erosion and those of

submersion is the most important and the most distinctive, and furnishes, I think, what may be termed a diagnosis character of lakes of erosion. In most river valleys through a hilly or mountainous country outside of the glaciated districts, the tributary streams entering more or less at right angles to the main valley are seen to occupy small valleys of their own, which usually open out for a short distance at the same level before joining the main valley. Of course there are also torrents which rush down steep mountain slopes directly to the main river, but even these have usually cut ravines more or less deeply into the rock. Now if in such a valley we could mark out a contour line 200, 300, or 500 feet above the level of the main stream, we should see that line continually turning up each side valley or ravine till it reached the given level at which to cross the tributary stream, and then turning back to the main valley. The contour line would thus form a series of notches or loops of greater or less depth at every tributary stream with its entering valley or deeply cut ravine, and if the main valley were filled with water this line would mark out the margin of the lake. As an illustration of this feature we may take the southwest coast of England, which has never been glaciated, but which has undergone a slight recent subsidence as indicated by the submerged forests which occur at several places. The result of this submergence is that the lower parts of its larger river valleys have been converted into inland tidal lakes, such as Poole Harbor, Dartmouth Harbor, Kingsbridge River, Plymouth and Devonport Harbors, and Carrick Road above Falmouth. The Dart River is an excellent example of such a submerged valley, and its outline at high-water mark is shown at (3) on the accompanying illustration (Plate XV), where the characteristic outline of such a valley is well indicated, the water running up every tributary stream as described above. The lower section (4) shows the same feature by means of a map of the River Tweed, near Peebles, with the 700 feet contour line marked on it by a dotted line.* If the valley were submerged to this depth the dotted line would mark the outline of a lake, with arms running up every tributary stream just as in the case of the river Dart. Although situated in a glaciated district the valley here is post-glacial, all the old river channels being deeply buried in drift.

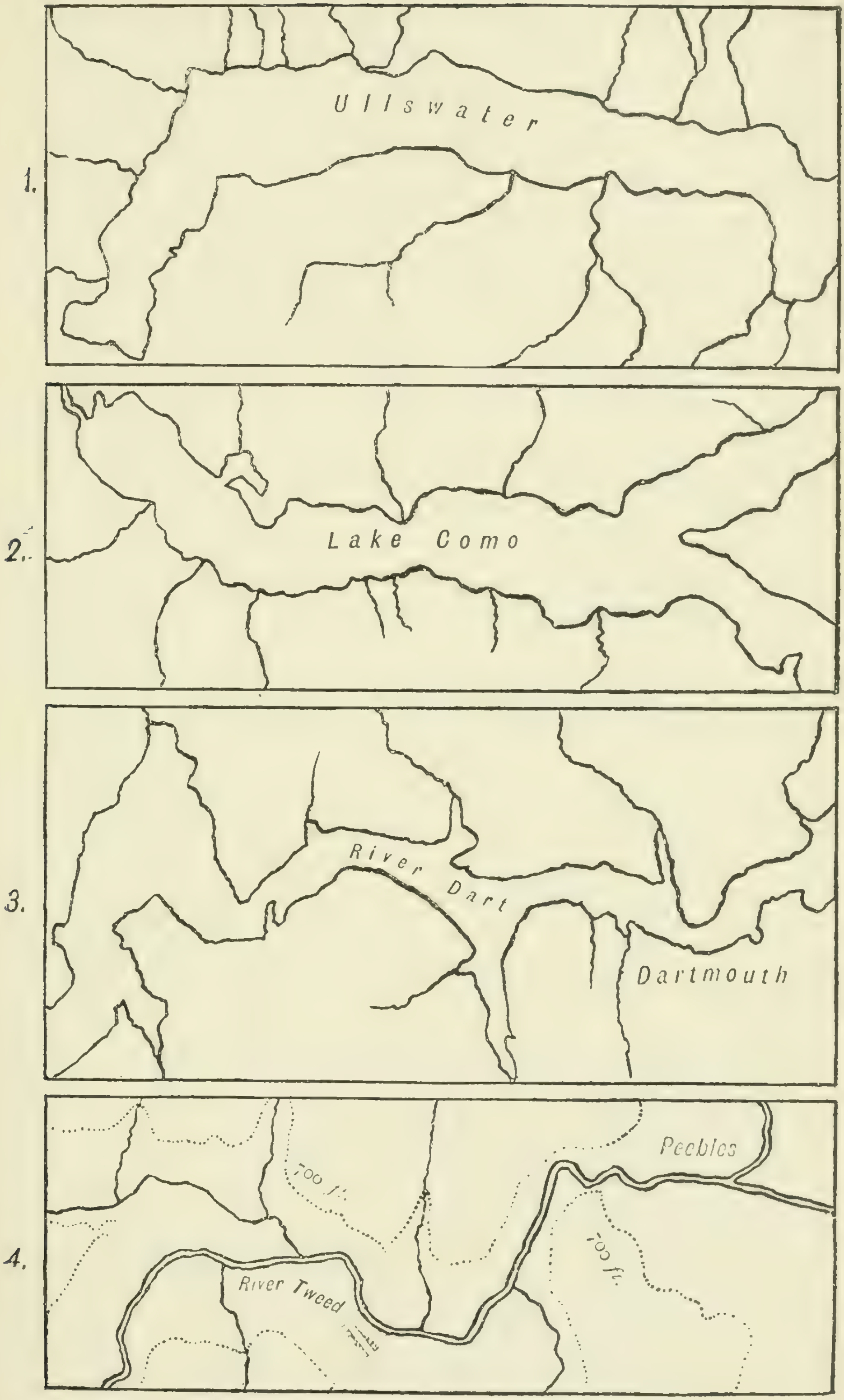
If we now turn to the valley lakes in glaciated districts we shall find that they have a very different contour, as shown by the two upper outline maps on Plate XV; (1) showing the upper part of Ullswater on a scale of 1 mile to an inch, as in the Dart and Tweed maps, and (2) showing the upper part of Lake Como, taken from the Alpine Club map, on a scale of 4 miles to an inch. In both of these it will be seen that the water never forms inlets up the inflowing streams, but all of these without exception form an even junction with the lake margin,

* Copied from a portion of the map at p. 144 of Geikie's *Great Ice Age,* taken from the Ordnance Survey Map.

just as they would do if flowing into a river. Exactly the same feature is present in the lower portions of these two lakes, and it is equally a characteristic of every lake in the lake district, and of all the Swiss and Italian lakes. On looking at the maps of any of these lakes one can not but see that the lake *surface*, not the lake *bottom*, represents approximately the level of the pre-glacial valley, and that the lateral streams and torrents enter the lake in the way they do because they could only erode their channels down to the level of the old valley before the ice overwhelmed it. Of course this rule does not apply to large tributary valleys carrying separate glaciers, since these would be eroded by the ice almost as deeply as the main valley. - - -

The Lake of Geneva as a test of the rival theories.—When I recently began to study this question anew I was inclined to think that the largest and deepest of the Alpine lakes, such as Geneva, Constance, Lago Maggiore, and Lago di Garda, might perhaps have originated from a combination of earth movements with ice erosion. But on further consideration it appears that all the characteristic features of erosion are present in these as fully as in the smaller lakes. They are situated in the largest river valleys or in positions of greatest concentration of the glacier streams; their contours and outlines are those of eroded basins; while all the difficulties in the way of an origin by earth movements are as prominent in their case as in that of any other of the lakes. I will therefore discuss, first, some of the chief objections to the erosion theory as applied to the above-named lake, and then consider the only alternative theory that has obtained the acceptance of modern writers.

One of the first objections made was that the lake did not lie in the direction of the greatest action of the glacier, which was straight across to the Jura, where the highest erratic blocks are found. This was urged by Sir Charles Lyell immediately after Ramsay's paper was read, and as it has quite recently been put forth by Prof. Bonney, it would appear to be thought to be a real difficulty. Yet a little consideration will show that it has not the slightest weight. No lake was eroded in the line of motion of the central and highest part of the old glacier, because that line was over an elevated and hilly plateau, which is even now from 500 to 1,000 feet above the lake, and was then still higher, since the ice sheet certainly effected some erosion. The greatest amount of erosion was of course in the broad and nearly level valley of the pre-glacial Rhone, which followed the great curve of the existing lake, and had produced so open a valley *because the rocks in that direction were easily denuded.* Objectors invariably forget or overlook the indisputable fact that the existence of a broad, open, flat-bottomed valley in any part of a river's course proves that the rocks were there either softer, or more friable, or more soluble, or, by some combination of characters, more easily denuded. A number of favorable conditions were combined to render ice erosion easy in such a valley.



LAKE FORMS DUE TO EROSION (1, 2); TO SUBMERSION (3, 4).

The rock was, as we have shown, more easy to erode; owing to the low level the ice was thicker and had greater weight there than elsewhere: owing to the flatness and openness of the valley the ice moved more freely there: owing to the long previous course of the glacier its under surface would be heavily loaded with rock and grit, which, during its whole course, would, by mere gravitation, have been slowly working its way downward to the lowest level; and, lastly, all the sub-glacial torrents would accumulate in this lowest valley, and as erosion went on would, under great hydrostatic pressure, wash away all the ground-out material, and so facilitate erosion.

Another objection almost equally beside the real question is to ask why the deepest part of the lake is near the south or convex side, whereas a stream of water always exerts most erosive force against the concave side.* The answer is, that ice is not water, and that it moves so slowly as to act, in many respects, in quite a different manner. Its greatest action is where it is deepest, in the middle of the ice stream, while water acts least where it is deepest, and more forcibly at the side than in the middle. The lake is no doubt deepest in the line of the old river, where the valley was lowest; and that may well have been nearer the southern than the northern side of the lake.

Another frequently-urged objection is, that as the glacier has not widened the narrow valley from Martigny to Bex it could not have eroded a lake nearly a thousand feet deep. This seems to me a complete *non sequitur*. As a glacier erodes mainly by its vertical pressure and by the completeness of its grinding armature of rock, it is clear that its grinding power laterally must have been very much less than vertically, both on account of the smaller pressure because it would mold itself less closely to the ever-varying rocky protuberances, and mainly, perhaps, because at the almost vertical sides of the valley it would have a very small stony armature, the blocks continually working their way downward to the bottom. Thus, much of the ice in contact with the sides of narrow ravines might be free of stones, and would therefore exert hardly any grinding power. It is also quite certain that the ice in this narrow valley rose to an enormous height, and that the chief motion and also the chief erosion would be on the lateral slopes· while the lower strata, wedged in the gorge, would be almost stationary.

The most recent researches, according to M. Falsan, show that the thickness of the ice has been usually under-estimated. A terminal moraine on the Jura at Chasseron is 4,000 feet above the sea, or 2,770 feet above Geneva. In order that the upper surface of the ice should have had sufficient incline to flow onward as it did it was probably 5,000 or 6,000 feet thick below Martigny and 4,000 or 5,000 feet over the middle of the lake. It is certain, at all events, that whatever

* Falsan, *La Période Glaciaire*, p. 153. Fabre, *Origine des Lacs Alpins*, p. 4.

thickness was necessary to cause onward motion that thickness could not fail to be produced, since it is only by the onward motion to some outlet or lowland where the ice can be melted away as fast as it is renewed that indefinite enlargement of a glacier is avoided. The essential condition for the formation of a glacier at all is that more ice should be produced annually than is melted away. So long as the quantity produced is on the average more than that melted, the glaciers will increase; and as the more extended surface of ice, up to a certain point, by forming a refrigerator, helps its own extension, a very small permanent annual surplus may lead to an enormous extension of the ice Hence, if at any stage in its development the end of a glacier remains stationary, either owing to some obstacle in its path or to its having reached a level plain where it is unable to move onward, the annual surplus of ice produced will go to increase the thickness of the glacier and its upper slope till motion *is* produced. The ice then flows onward till it reaches a district warm enough to bring about an equilibrium between growth and dissolution. If, therefore, at any stage in the growth of a glacier, a thickness of 6,000, 7,000, or even 8,000 feet is needed to bring about this result, that thickness will inevitably be produced. - - -

In view therefore of the admitted facts, all the objections alleged by the best authorities are entirely wanting in real force or validity; while the enormous size and weight of the glacier and its long duration, as indicated by the great distance to which it extended beyond the site of the lake, render the excavation by it of such a basin as easy to conceive as the grinding out of a small alpine tarn by ice not one-fourth as thick, and in a situation where the grinding material in its lower strata would probably be comparatively scanty.

We have now to consider the theory of Desor, adopted by M. Favre, and set forth in the recent work of M. Falsan as being "more precise and more acceptable" than that of Ramsay. We are first made acquainted with a fact which I have not yet alluded to, and which most writers on the subject either fail to notice or attempt to explain by theories, as compared with which that of Ramsay is simple, probable, and easy of comprehension. This fact is, that around Geneva at the outlet of the lake, as well as at the outlets of the other great lakes, there is spread out an *old alluvium* which is always found *underneath the bowlder clay and other glacial deposits.* This alluvium is moreover admitted to be formed in every case of materials largely derived from the great Alpine range. Now here is a fact which of itself amounts to a demonstration that the lakes *did not exist* before the ice age; because, in that case all the Alpine débris would be intercepted by the lake (as it is now intercepted) and the alluvium below the glacial deposits would be, in the case of Geneva, that formed by the wash from the adjacent slopes of the Jura, while in every case it would be local not Alpine alluvium. - - -

Summary of the evidence.—As the subject here discussed is very complex, and the argument essentially a cumulative one, it will be well briefly to summarize its main points.

In the first place, it has been shown that the valley lakes of highly glaciated districts form a distinct class, which are highly characteristic, if not altogether peculiar, since in none of the mountain ranges of the tropics or of non-glaciated regions over the whole world are any similar lakes to be found.

The special conditions favorable to the erosion of lake basins and the mode of action of the ice tool are then discussed, and it is shown that these conditions have been either overlooked or ignored by the opponents of the theory of ice erosion.

The objections of modern writers are then considered, and they are shown to be founded either on mistaken ideas as to the mode of erosion by glaciers, or on not taking into account results of glacieration which they themselves either admit or have not attempted to disprove.

The alternative theory—that earth-movements of various kinds led to the production of lake basins in all mountain range, and that those in glaciated regions were preserved by being filled with ice—is shown to be beset with numerous difficulties, physical, geological, and geographical, which its supporters have not attempted to overcome. It is also pointed out that this theory in no way explains the occurrence of the largest and deepest lakes in the largest river valleys, or in those valleys where there was the greatest concentration of glaciers, a peculiarity of their distribution which points directly and unmistakably to ice erosion.

A crucial test of the two theories is then suggested, and it is shown that both the sub-aqueous contours of the lake basins, and the superficial outlines of the lakes, are exactly such as would be produced by ice erosion, while they could not possibly have been caused by submergence due to any form of earth movements. It is submitted that we have here a positive criterion, now adduced for the first time, which is absolutely fatal to any theory of submersion.

Lastly, the special case of the Lake of Geneva is discussed, and it is shown that the explanation put forth by the anti-glacialists is wholly unsupported by facts and is opposed to the known laws of glacier motion. The geologists who support it themselves furnish evidence against their own theory in the ancient alluvium at Geneva on which the glacial deposits rest, and which is admitted to be mainly derived from the distant Alps. But as all alluvial matter is necessarily intercepted by large and deep lakes, the presence of this Alpine alluvium immediately beneath the glacial débris at the foot of the lake indicates that the lake did not exist in preglacial times, but that the river Rhone flowed from the Alps to Geneva, carry with it the old alluvium, consisting of mud, sand, and gravel, which it had brought down from the mountains. Still more conclusive however is the fact that the three special features

which have been shown to indicate erosion rather than submergence are present in this lake as fully as in all other Alpine valley lakes and unmistakably point to the glacial origin of all of them.

On the whole, I venture to claim that the facts and considerations set forth in this paper show such a number of distinct lines of evidence, all converging to establish the theory of the ice erosion of the valley lakes of highly glaciated regions—a theory first advocated by the late Sir Andrew Ramsay—that that theory must be held to be established, at all events provisionally, as the only one by which the whole body of the facts can be explained and harmonized.

GEOLOGIC TIME, AS INDICATED BY THE SEDIMENTARY ROCKS OF NORTH AMERICA.*

By CHARLES D. WALCOTT.

INTRODUCTION.

Of all subjects of speculative geology few are more attractive or more uncertain in positive results than geologic time. The physicists have drawn the lines closer and closer until the geologist is told that he must bring his estimates of the age of the earth within the limit of from 10,000,000 to 30,000,000 years. The geologist masses his observations and replies that more time is required, and suggests to the physicist that there may be an error somewhere in his data or the method of his treatment. The geologist realizes that geologic time can not be reduced to actual time in decades or centuries; there are too many partially recognized or altogether unknown factors; but he can approximate the relative position of certain formations and, by comparison of their sediments, dimensions, and contained record of life with the estimated rates of denudation, sedimentation, and organic growth, form a general estimate of their relative time duration. It is my purpose to-day to take up the consideration of the evidence afforded by the sedimentary rocks of our continental area, and largely of a distinct basin of sedimentation, with a view of arriving, if possible, at an approximate time period for their deposition. Before proceeding to examine the conditions of denudation, sedimentation, etc., that enter as factors into the calculation of the age of the earth on the basis of sedimentary geology, we will refer to some of the opinions that have been held by geologists on geologic time and the age of the earth.

Soon after geology emerged from its pre-systematic stage and assumed an independent position among the inductive sciences speculations on the age of the earth were made by both geologists and physicists. Hutton, Werner, Smith, and Cuvier, among the former, arranged and published their observations and those of their predecessors during the closing years of the eighteenth century, and in the three succeeding decades rapid progress was made in many lines of investigation by

* Vice-presidential address before section E, American Association for the Advancement of Science, Madison, Wis., August 17, 1893.

numerous observers, and the literature of geology was enlarged by contributions dealing with nearly every phase of the subject.

Hutton.—Dr. James Hutton was the founder of physical geology and the predecessor of Lyell in advocating the uniformitarian theory of geology. It is, in a great measure, true—as Lyell has well said of Hutton's attempt to give fixed principles to geology—that "too little progress has been made toward furnishing the necessary data to enable any philosopher, however great his genius, to realize so noble a project."* In his first memoir Hutton† speaks of a method of measuring the duration of geologic time as follows:

"We are investigating the age of the present earth, from the beginning of that body, which was in the bottom of the sea, to the perfection of its nature, which we consider as in the moment of our existence; and we have necessarily another era, which is collateral, or correspondent, in the progress of those natural events. This is the time required, in the natural operations of this globe, for the destruction of a former earth, an earth equally perfect with the present and an earth equally productive of growing plants and living animals. Now, it must appear that it we had a measure for one of those corresponding operations we would have an equal knowledge of the other.

* * * * * * *

"The highest mountain may be levelled with the plain from whence it springs without the loss of real territory in the land; but when the ocean makes encroachment on the basis of our earth, the mountain, unsupported, tumbles with its weight; and with that accession of hard bodies, movable with the agitation of the waves, gives to the sea the power of undermining farther and farther into the solid basis of our land. This is the operation which is to be measured; this is the mean proportional by which we are to estimate the age of worlds that have terminated, and the duration of those that are but beginning."

He then discusses the data for estimating the length of time it has taken for a specific amount of erosion, and concludes "that all the coasts of the present continents are wasted by the sea, and constantly wearing away upon the whole; but this operation is so extremely slow that we cannot find a measure of the quantity in order to form an estimate. Therefore, the present constituents of earth, which we consider as in a state of perfection, would, in the natural operations of the globe, require a time indefinite for their destruction."

He believed that the continents thus destroyed were formed from the ruins of pre-existing continents, and that there were records of three such periods, each of which, in our measurement of time, were of indefinite duration.‡

Lyell.—In 1830 Sir Charles Lyell began to publish the results of his profound and philosophical studies of geologic phenomena. He firmly established the broad outlines of the law of uniformity as opposed to

* *Principles of Geology,* 12th Ed., 1875, vol. I, p. 73.

† Theory of the Earth; or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe. *Trans. Roy. Soc. Edinburgh,* 1788, vol. I, pp. 297, 298.

‡ *Loc. cit.,* p. 304.

the doctrine of geologic catastrophes and rendered possible a rough computation of the age of the earth on the principle that geologic processes were the same during geologic time as at the present. Before this effort the scientist and theologian (with the exception of Hutton and his followers) vied with each other in their attempts to harmonize the Mosaic record with that of nature: they expanded the seventeenth century views of the former and contracted the inductive reasoning from geologic phenomena, and called in the aid of special creations, great catastrophes and other unusual phenomena. This was cleared away among geologists by Lyell's work, supplemented later by the general law of evolution which, since the appearance of Darwin's Origin of Species, has with a few and rare exceptions controlled and directed scientific work and thought in this direction.

Lyell based an argument for the age of the sedimentary rocks as known to him on the rate of modification of the species of mollusca since the beginning of the "Cambrian period." He divided the geologic series into twelve periods and estimated that 20,000,000 years were demanded for a complete change in the species of each period, or 240,000,000 years in all. This estimate excluded the Primordial of Barrande and the "antecedent Laurentian formations."*

Darwin.—In the chapter summing up the imperfections of the geological record Darwin concludes that, if his theory of the origin of species is true, "it is indisputable that before the lowest Cambrian stratum was deposited, long periods elapsed, as long as, or probably far longer than, the whole interval from the Cambrian age to the present day; and that during these vast periods the world swarmed with living creatures." When mentioning the opinions of various authors on the duration of geologic time, he indirectly gives his own views, as follows:

"Mr. Croll estimates that about 60,000,000 years have elapsed since the Cambrian period, but this, judging from the small amount of organic change since the commencement of the Glacial epoch, appears a very short time for the many and great mutations of life which have certainly occurred since the Cambrian formation; and the previous 140,000,000 years can hardly be considered as sufficient for the development of the varied forms of life which already existed during the Cambrian period. It is however probable, as Sir William Thompson insists, that the world at a very early period was subjected to more rapid and violent changes in its physical conditions than those now occurring; and such changes would have tended to induce changes at a corresponding rate in the organisms which then existed."†

Houghton.—Rev. Samuel Houghton, in commenting on the geological calculus, states that he believes that the time during which organic life has existed on the earth is practically infinite. On the basis of the time of cooling he assigns an age of 1,280,000,000 years for the Azoic period and remarks that the globe was habitable, in part at least, for a longer

* *Principles of Geology*, 10th ed., 1867, vol. I, p. 301.

† *Origin of Species*, American ed., from 6th Eng. ed., 1882, p. 286.

period.* At a later date, when attempting to assign a minor limit to the duration of geologic time, he was driven to the conclusion that geologic climates are due to the combined cooling of the earth and sun. On comparing the rates of cooling of such a body as the earth with the maximum measured thickness of the several strata, there is a remarkable proportion between them, which leads toward the conclusion that the maximum thickness of the strata is proportional to the times of their formation. From the combined conclusions deduced from the rate of cooling of the earth and the time required for deposition of the sedimentary rocks, he gives for the whole duration of geologic time a minimum of 200,000,000 years.†

Croll.—Dr. James Croll began his studies of denudation as a factor in estimates of geologic time in 1865, and reference is made to it in 1867.‡ In the following year a more elaborate paper was published, and subsequently numerous references have been made to it and other factors that are to be considered in the estimate of geologic time.§ Dr. Croll agrees with Sir W. Thompson that Prof. Tait probably under-estimated the time when he affirms that 10,000,000 years is about the utmost that can be allowed, from the physical point of view, for all the changes that have taken place in the earth's surface since vegetable life of the lowest known form was capable of existing there. He remarks:

"And this is certainly all that ever can be expected from gravitation: mathematical computation has demonstrated that it can give no more. The other theory, founded on motion in space—a cause as real as gravitation—labors under no such limitation. According to it, so far at least as regards the store of energy which may have been possessed by the sun, plant and animal life may date back, not to 10,000,000 years, but to a period indefinitely more remote. In fact, there is as yet no known limit to the amount of heat which this cause may have produced; for this depended upon the velocities of the two bodies at the moment prior to collision, and what these velocities were we have no means of knowing. They might have been 500 miles a second, for anything which can be shown to the contrary. Of course, I by no means affirm that it is as much as 100,000,000 years since life began upon our earth, but I certainly do affirm that, in so far as a possible source of the sun's energy is concerned, life may have begun at a period as remote."||

Dr. Croll considers the geological evidence relating to the age of the sun's heat on the principle that, "in order to determine the present rate of sub-aerial denudation, we have only to ascertain the quantity of sediment annually carried down by the river systems."* After extended consideration of the evidence he concludes that a period of 24,000,000

* *Manual of Geology*, 3d ed., 1871, p. 101.

† *Nature*, July 4, 1878, vol. XVIII, pp. 267, 268.

‡ *Phil. Mag.*, Feb. 1867, vol. XXXIII, p. 130.

§ *Phil. Mag.*, London, May, 1868, vol. XXXV, pp. 363–384; Nov., 1868, vol. XXXVI, pp. 362–386. *Geol. Mag.*, London, 1871, pp. 97–102. *Climate and Time*, London, 1875, pp. 329–367. *Stellar Evolution and its Relations to Geological Time*, 1889, pp. 39–68.

|| *Evolution and its Relations to Geological Time*, 1889, p. 36.

years would be required for the deposition of the known sedimentary rocks. On the theory that the present existing sedimentary rocks have on the average passed at least twice through the cycle of destruction and reformation the period is multiplied by three, which results in 72,000,000 years for the time of duration since the beginning of the deposition of the sedimentary rocks. He says further, "It is impossible to tell from geological data the actual age of the stratified rocks; but this is not required. What we require is, as already stated, not their actual age but an inferior limit to that age."

Wallace.—The chapter on "The earth's age" contained in Sir A. R. Wallace's Island Life, is an admirable summary of his own views and those of various geologists, naturalists, and physicists who have written on the subject. From the consideration of data bearing on the denudation and deposition of strata as a measure of time he thinks that 28,000,000 years will be sufficient for the deposition of the known sedimentary rocks. Of the value of this estimate he says, "It is not of course supposed that the calculation here given marks any approach to accuracy, but it is believed that it does indicate the order of magnitude of the time required. We have a certain number of data, which are not guessed, but the result of actual measurement; such are, the amount of solid matter carried down by rivers, the width of the belt within which this matter is mainly deposited, and the maximum thickness of the known stratified rocks." †

By adopting Croll's theory of glacial epochs occurring at certain periods of great eccentricity, several datum points are secured by Wallace that are correlated with certain geologic phenomena of the Tertiary and Pleistocene periods and the probable date of the Miocene period. He then takes the ratio of Lyell for the duration of the geologic epochs and concludes that 16,000,000 years have passed since Cambrian time. On the basis of Dana's theory that the Tertiary is only one-fifteenth of the Mesozoic and Paleozoic combined, the result is 60,000,000 years for the same interval. Of these figures he says:

"The estimate arrived at for the rate of denudation and deposition (28,000,000 years) is nearly midway between these, and it is, at all events, satisfactory that the various measures result in figures of the same order of magnitude, which is all one can expect on so difficult and exceedingly speculative a subject. The only value of such estimates is to define our notions of geological time, and to show that the enormous periods of hundreds of millions of years, which have sometimes been indicated by geologists, are neither necessary nor warranted by the facts at our command; while the present result places us more in harmony with the calculation of physicists, by leaving a very wide margin between geological time as defined by the fossiliferous rocks, and that far more extensive period which includes all possibility of life upon the earth." ‡

* *Stellar Evolution, and its Relations to Geological Time*, 1889, p. 39.

† *Island Life*, 2d ed., 1892, pp. 222, 223.

‡ *Loc. cit.*, pp. 235, 236.

The results obtained by Wallace are questioned by T. Mellard Reade, who states that Wallace has not allowed for the erosion and re-deposition of the same sediments a number of times.*

Winchell.—Dr. Alexander Winchell reviews the opinions of physicists and geologists on the age of the world or of certain periods, and enumerates the grounds for the various estimates, as follows:

"(1) The time required for the sun to contract from a nebulous condition or from the orbit of the earth to its present limits.

"(2) The time which the sun will require to cool from its present condition to a darkened or planetary state.

"(3) The time required for the earth to cool from incipient incrustation to its present state, based on the thermal conductivity of rock masses and the rate of increased heat toward the earth's center.

"(4) Relative times required for the deposition of all the rocky sediments.

"(5) Calculation based on the obliteration of the rotational effects of the upheaval of a continental mass.

"(6) The time since the middle of the last glacial period, based on the theory that epochs of glaciation on the northern hemisphere have been caused by extreme eccentricity of the earth's orbit.

"(7) Estimates based on rates of erosions and deposition.

"(8) The rate of Bluff-recession and Terrace formation.

"(9) Decrease of temperature of ground covered by ice during the glacial period, as compared with temperature of ground not chilled by the ice sheet."†

Dr. Winchell was inclined to accord at least equal confidence to the later results of geologic action, such as erosion of river gorges and lakeside and seaside bluffs, as he would give to the mathematical methods of the physicist. On this basis he deduced the result that the whole incrusted age of the world would be 3,000,000 years. In conclusion he says:

"If our attempts to ascertain the age of the world, or the duration of any single period of its evolution, yield only uncertain results, they suffice at least to demonstrate that geological history has limits far within the wild conceptions of a certain class of geologists. They show, if we may credit the indications here regarded most trustworthy, a restriction of the modern epoch within limits not exceeding one-tenth or one-twentieth the duration sometimes assigned to it."‡

Geikie.—Sir Archibald Geikie has recently summed up the case of the geologist and physicist in a very clear statement, as follows:

"In scientific as in other mundane questions there may often be two sides, and the truth may ultimately be found not to lie wholly with either. I frankly confess that the demands of the early geologists for an unlimited series of ages were extravagant, and even, for their own purposes, unnecessary, and the physicist did good service in reducing them. It may also be freely admitted that the latest conclusions from physical considerations of the extent of geological time require that the interpretation given to the record of the rocks should be vigorously revised, with the view of ascertaining how far that interpretation may

* *Geol. Mag.*, 1883, vol. x, pp. 309, 310.

† *World Life, or Comparative Geology*, Chicago, 1883, pp. 355–376.

‡ *Loc. cit.*, p. 378.

be capable of modification or amendment. But we must also remember that the geological record constitutes a voluminous body of evidence regarding the earth's history which can not be ignored, and must be explained in accordance with ascertained natural laws. If the conclusions derived from the most careful study of this record can not be reconciled with those drawn from physical considerations, it is surely not too much to ask that the latter should be also revised. It has been well said that the mathematical mill is an admirable piece of machinery, but that the value of what it yields depends upon the quality of what is put into it. That there must be some flaw in the physical argument, I can, for my own part, hardly doubt, though I do not pretend to be able to say where it is to be found. Some assumption, it seems to me, has been made, or some consideration has been left out of sight, which will eventually be seen to vitiate the conclusions, and which, when duly taken into account, will allow time enough for any reasonable interpretation of the geological record."*

Of the rate of denudation and deposition he says:

"The rate of deposition of new sedimentary formations, over an area of sea floor equivalent to that which has yielded the sediment, may vary from 1 foot in 730 years to 1 foot in 6,800 years. If now we take these results and apply them as measures of the length of time required for the deposition of the various sedimentary masses that form the outer part of the earth's crust, we obtain some indication of the duration of geological history. On a reasonable computation these stratified masses, where most fully developed, attain a united thickness of not less than 100,000 feet. If they were all laid down at the most rapid recorded rate of denudation, they would require a period of 73,000,000 years for their completion. If they were laid down at the slowest rate they would demand a period of not less than 680,000,000." †

Reade.—Mr. T. Millard Reade has been a large contributor to the literature of geologic time, both directly and indirectly. His most recent conclusion is that there appears to be a consensus of opinion that 1 foot in 3,000 years is a fair estimate of the mean rate of such erosion over all land areas throughout all geologic time. The calculation that has elapsed since the beginning of Cambrian time, on this basis, is stated as follows:

"The mean area of denudation throughout post-Archaean times being taken as one-third the entire land areas of the globe, the bulk of the post-Archean rocks being expressed by the land area of the globe 2 miles thick, and the rate of denudation 1 foot in 3,000 years, the time of accumulation will be $5{,}280 \times 2 \times 3{,}000 \times 3 = 95{,}040{,}000$. The time that has elapsed since the commencement of the Cambrian is, therefore, in round figures, 95,000,000 years." ‡

Speaking of Sir Archibald Geikie's conclusion that the earth's age, geologically speaking, must be somewhere between 100,000,000 and 600,000,000 years, he says:

"This is a large margin, no doubt, but it is an important thing to

* Presidential Address. Report Sixty-second Meeting Brit. Assoc. Adv. Sci., 1892, pp. 19, 20. (Also Smithsonian Report for 1892, pp. 125, 126.)

† *Loc. cit.*, p. 21.—Sm. Report, 1892, p. 127.

‡ "Measurement of geological time." *Geol. Mag.*, 1893, vol. x, pp 99, 100.

know. Different men may put different value on the three factors, bulk of sediment, rate of denudation, and area of denudation; but I think a fair and impartial examination of the reasoning involved in this paper will show that the principle of the calculation is sound.

"It must not be forgotten that to arrive at the earth's age Archæan time has to be added to my estimate of 95,000,000 years, which very materially increases the margin of geologic time on which we are allowed to draw."*

In an earlier paper Reade assembles much valuable data on chemical denudation,† and later reviews the results obtained by the geologist and the mathematician. ‡

M. A. de Lapparent is one of the few European continental geologists who have written on geologic time. On the basis of mechanical denudation and sedimentation he thinks that from 67,000,000 to 90,000,000 years, at the present rate of sedimentation, would account for everything that has been produced since the consolidation of the crust.§

Dana.—In some observations on the length of geologic time, Prof. James D. Dana says that geology has no means of substituting positive lengths of time in place of the time ratios he has deduced from the relative thicknesses of the rock series pertaining to the several geologic ages, but that it affords facts sufficient to prove the general proposition that geologic "*time is long.*" He cites examples, such as the retreat of Niagara Falls and the recent growth of coral reefs. According to his time ratio, if 48,000,000 years is assigned since the commencement of the Silurian, the Paleozoic, Mesozoic, and Cenozoic time would represent, respectively, 36,000,000, 9,000,000, and 3,000,000 years.||

McGee.—In an article on comparative chronology by Mr. W J McGee, the conclusion is reached that the antiquity of the glacial deposits margined by the great terminal moraine is about 7,000 years, and of the Columbian formation and of the ice invasion to which it is ascribed, 200,000 years, and of the Lafayette formation of late Tertiary age, 10,000,000 years. On this basis the mean estimate of the age of the earth is 15,000,000,000 years, and 7,000,000,000 years have elapsed since the beginning of Paleozoic time.¶ In a subsequent "Note on the Age of the Earth" Mr. McGee modifies his former statement, and gives as a mean estimate of the age of the earth 6,000,000,000 years, and of the duration of time since the beginning of the Paleozoic, 2,400,000,000 years, which is based on a minimum estimate for the age of the earth of

* "Measurement of Geological Time." *Geolog. Mag.*, 1893, vol. x, p. 100.

† *Proc. Liverpool Geol. Soc.*, 1877, vol. III, pl. iii, pp. 211–235.

‡ *Geol. Mag.*, 1878, vol. v, pp. 145–164.

§ De la mesure du temps par les phénomènes de sédimentation. *Bull. Soc. Géol. France*, 1890, 3d ser., vol. XVIII, pp. 351–355. La destinée de la terre ferme, et durée des temps géologiques. Revue des questions scientifiques, July, 1891. Pamphlet, Bruxelles, pp. 1–38.

|| *Manual of Geology*, 2d ed., pp. 690, 591.

¶ *Am. Anthropologist*, 1892, vol. v, p. 340.

10,000,000 years and a maximum estimate of 5,000,000,000,000 [5 thousand million] years.* Mr. McGee, in speaking of these estimates, says:

"These general estimates are indefinite, and the minima, mean, and maxima are alike unworthy of final acceptance; but they stand for a real problem and not a merely ideal one, and represent actual conditions of the known earth; and, so far as the science of geology is concerned, the maximum estimate is quite as probable as the minimum, while the mean is much more probable than either." †

Upham.—Prof. Warren Upham, after reviewing various estimates of geologic time, concludes that the "probable length of Glacial and Post-Glacial time together is 30,000 or 40,000 years, more or less; but an equal or considerably longer preceding time, while the areas that became covered by ice were being uplifted to high altitudes, may perhaps with good reason be also included in the Quaternary era, which then would comprise some 100,000 years." He then applies Prof. Dana's time ratios and concludes that the time needed for the earth's stratified rocks and the unfolding of its plant and animal life must be about 100,000,000 years.‡ Mr. Upham's paper gives a number of illustrations of geologic phenomena from Tertiary and Pleistocene geology that bear upon the time duration of these epochs.

From the foregoing estimates of geologic time, the only conclusion that can be drawn is that the earth is *very old*, and that man's occupation of it is but a day's span as compared with the eons that have elapsed since the first consolidation of the rocks with which the geologist is acquainted.

When I began the preparation of this paper it was my intention to carefully analyze the sedimentary rocks of the entire geologic series as exposed upon the North American continent. I soon found, however, that the time at my disposal would make this impracticable, and I decided to take up the history of the deposits that accumulated in Paleozoic time on the western side of our continent, in an area that for convenience I shall call the Cordilleran sea. This was chosen because (1) I was personally acquainted with many of its typical sections, (2) there was a broad and almost uninterrupted sedimentation during Paleozoic time, and (3) there was a prospect for obtaining more satisfactory data as a basis of calculation, since calcareous deposits are in excess of those of mechanical origin.

We will now consider several points in relation to the growth or evolution of the North American continent, as the deposition of mechanical sediments depend to a considerable extent on the character of the adjoining land area, and chemical sedimentation is also influenced by it.

GROWTH OF THE CONTINENT.

The Algonkian sediments were deposited in interior and bordering seas that filled the depressions and extended over the margins of the

* *Science*, June 9, 1893, vol. XXI, p. 309.

† *Loc. cit.*, p. 310.

‡ *Am. Jour. Sci.*, 1893, vol. XLV, pp. 217, 218.

Archean continent. From the great thickness of mechanical sediments it was evidently a period of elevated land and rapid denudation. With the close of Algonkian time extensive orographic movements occurred that outlined the subsequent development of the continent. The lines of the Rocky mountain and Appalachian ranges were emphasized and the great basins of sedimentation west of them defined. Subsequent movements have elevated the old and formed new subparallel ranges. These movements were often of long duration and also separated by great intervals of time, as is shown by the long continued base levels of erosion during which the great thickness of calcareous deposits accumulated in the Cordilleran and Appalachian seas. Since Algonkian time the growth of the continent has been by the deposition of sediments in the bordering oceans and interior seas and lakes within the limits of the continental plateau; and it is considered that the relative position of the continental plateau and the deep sea have not materially changed during that period. How much the deposits on the continental border have increased its area is unknown, as at present they are largely concealed beneath the waters of the ocean. During Paleozoic time the two areas of greatest known accumulation were the Appalachian and Cordilleran seas, where 30,000 feet or more of sediments were deposited. In the Cordilleran sea sedimentation was practically uninterrupted (except during a short interval in middle Ordovician time) until towards the close of Paleozoic time. In the northern Appalachian sea it continued without any marked unconformity, from early Cambrian to the close of Ordovician time, and, south of New York, with relatively little interruption, until the close of Paleozoic time. Certain minor disturbances occurred along the eastern border of the sea, but they were not of sufficient extent to affect a general conclusion—which is that the depression of the areas of deposition within the continental platform continued without reversal of the subsidence during Paleozoic time. During Cambrian, and, it may be, late Algonkian, time, the extended interior Mississippian region was practically leveled by denudation, the eroded material being carried into the Cordilleran and Appalachian seas and, probably, to a sea to the south.

The sedimentation of the Mississippian area in Paleozoic time between the Appalachian and the Cordilleran seas was small as compared to that which accumulated in the latter. In Devonian time there does not appear to have been any sedimentation in the western portion of it west of the ninety-fourth meridian and east of the Cordilleran sea, and it was slight in the same interval in the Appalachian sea south of the thirty-seventh parallel.* There is little if any evidence in the sedi-

*The non-occurrence of Devonian sediment has not yet been fully explained. It has been suggested that the sea beyond the reach of mechanical sedimentation was too deep for the deposition of calcareous deposits. It is more probable that the sea was shallow and an area of non-deposition, or that its bed was raised to form a low, level land surface at a base level of erosion that was subjected to very slight degradation.

ments of Paleozoic time to show that they were deposited in the deep, open ocean; on the contrary, they were largely accumulated in partially inclosed seas or mediterraneans and on the borders of the continental plateau. The former is particularly true of the sedimentation of the Cordilleran and Appalachian seas and the broad Mississippian sea.

The close of the prolonged period of Paleozoic sedimentation was brought about by what Dana has termed the "Appalachian revolution." The topography of the continent was more or less changed, and the conditions of sedimentation that followed were unlike those that preceded. This revolution raised above the sea level a considerable portion of the Cordilleran and the Appalachian sea beds and also of the Mississippian sea, east of the ninety-sixth meridian and north of the thirty-fourth parallel. In its effect it may be compared to the Algonkian revolution* that preceded the deposition of the Paleozoic sediments.

With the opening of new conditions the sedimentation of the Meso zoic time began upon the Atlantic border and over large areas of the western half of the continent with the deposit of mechanical sediments—sands, silts, etc.—during Jura-Trias time. They are of a character that naturally follows a period of disturbance of pre-existing conditions and the formation of new basins of deposition with more or less elevated adjoining land areas. At its close orographic movements affecting the positions of the beds occurred upon the Pacific and Atlantic coasts and also, to a more limited degree, throughout the Rocky Mountain region. This does not appear to have extended over the plateau region or the central belt between the ninety-seventh and one hundred and fifth meridians.

The Cretaceous formations have their greatest development between the ninety-seventh and one hundred and twelfth meridians in Mexico and the United States, in a broad belt which extends from the boundary of the latter to the northwest into the British possessions as far as the sixty-first parallel. They were of a marine origin until toward the close of the period when a prolonged orographic movement elevated a large area of the continent above sea level and locally upturned the Cretaceous strata in the Rocky Mountain area. The shoaling of the sea was followed by the formation of great inland lakes in which fresh-water deposits succeeded the marine and estuarine sediments. Over the coastal regions they were of marine origin throughout.

The Tertiary sediments deposited on the Cretaceous are marine on the Atlantic, Gulf of Mexico, and Pacific coasts, and of fresh-water origin in the Rocky Mountain and Great Plains areas, where they were deposited in the great inland lakes outlined in the previous period.

* The term "revolution" is used to describe the culmination of a long series of phenomena that finally resulted in a distinctly marked epoch in the evolution of the continent. The "Appalachian revolution" began far back in the Paleozoic and culminated in the later stages of the Carboniferous, and the Algonkian revolution probably began far back in Algonkian time.

GEOGRAPHIC CONDITIONS ACCOMPANYING THE DEPOSITION OF PALEOZOIC SEDIMENTS IN THE CORDILLERAN SEA.

The assumed area of the Cordilleran or Paleo-Rocky Mountain sea includes over 400,000 square miles between the thirty-fifth and fifty-fifth parallels. To the eastward, during lower and middle Cambrian time, a land area is thought to have extended from east of the one hundred and eleventh meridian across the continent to the Paleo-Appalachian sea. This land was depressed toward the close of middle Cambrian time, and the Mississippian sea expanded over the wide plateau-like interior region, from the Gulf of Mexico on the south to the Lake Superior region on the north; westward it penetrated among the mountain ridges between the one hundred and fifth and one hundred and eleventh meridians, laying down the upper Cambrian deposits that are now found in New Mexico, Arizona, eastern Utah, the western half of Colorado, Wyoming, Idaho, and Montana, and still further north into Alberta and British Columbia. During Ordovician, Silurian, Devonian, and Carboniferous time this entire Mississippian region, except portions in Devonian time, appears to have been covered by a relatively shallow sea that was co-extensive with the Appalachian sea and that communicated freely with the Cordilleran sea. During this same age, however, the Rocky Mountain area of New Mexico, Colorado, Utah, Wyoming, and Montana formed a more or less well-defined boundary of ridges and islands between the Cordilleran and the interior sea up to the forty-ninth parallel. To the north of the latter the conditions appear to have been the same as on the eastern side of the continent, where the Appalachian sea communicated freely with the Mississippian sea. From the data that we now have I think that the Palezoic (Mississippian) sea extended at times over nearly all of the area subsequently covered by the Cretaceous and the later formations between the Gulf of Mexico and the Arctic ocean. This belt is bounded almost continuously on the east and west by Paleozoic rocks that extend from the Arctic ocean to Mexico, and whether of Cambrian, Ordovician, Silurian, or Devonian age they carry essentially the same fauna throughout their extent. In the outcrops of lower strata that rise up through this Cretaceous area the Cambrian, Ordovician, and Carboniferous rocks are found encircling the pre-Paleozoic rocks. Instances in which the Archean rocks have been met with immediately beneath the Cretaceous in borings in Dakota and Minnesota are along the eastern border of the area, next to the Archæan rocks, where it is probable that the Cretaceous overlaps the Paleozoic to the Archæan.

The western side of the Cordilleran sea seems to have been bounded by a land area that separated it from the Paleozoic sea, which extended through central California and the Pacific border of British Columbia and Vancouvers Island. From the position of the Carboniferous

deposits of California at the present time, it appears that this land varied from 100 to 150 miles in width and was practically continuous along the western side of the Cordilleran sea. This view is further strengthened by the fact that the Carboniferous fauna of California has certain characteristics which are not found in the Carboniferous of the Cordilleran area. Our knowledge of the conditions north of the fifty-fifth parallel is limited by the want of accurate geologic data. If Cambrian and Carboniferous rocks were not deposited in the Mackenzie River basin and also on the eastern side of the area now covered by Cretaceous strata, the inference is that during Cambrian and Carboniferous time there was a land area to the east and north of the northern Cordilleran sea that may have been tributary to the latter.

SOURCE OF SEDIMENTS DEPOSITED IN THE CORDILLERAN SEA.

The sediments deposited in every sea or lake are derived from land areas either by mechanical or chemical denudation.

Mechanical denudation results from the action of the waves and currents along the shore and the agency of rain, frost, snow, ice, wind, heat, etc., on the land. Rain is the most important factor and the result depends mainly upon its amount and the slope or the gradient of the land. The general average of denudation for the surface of the land areas of the globe, now usually accepted, is 1 foot in 3,000 years. This varies locally, according to Sir Archibald Geikie, from 1 foot in 750 years to 1 foot in 6,000 years.* Of the rate of denudation during Paleozoic time about the Cordilleran Sea we know very little, but I think that it was relatively rapid in early Cambrian time and during the deposition of the arenaceous sediments of the Ordovician and Carboniferous. The material forming the argillaceous shales of the Cambrian and Devonian was supplied to the sea more slowly. These conclusions are sustained by the slight change in the character of the faunas where interrupted by the sands and pebbles of the Ordovician and Carboniferous and the marked change between the base and summit of the argillaceous shales. As a whole, I think we are justified in assuming a minimum rate of mechanical denudation—of considerably less than 1 foot in 1,000 years—for the area tributary to the Cordilleran sea.

Chemical denudation is the removal of material taken into solution by water. Mr. T. Mellard Reade has discussed this phase of denudation in an admirable manner.† He came to the conclusion, from what was known of the water discharged into the ocean per year, the average amount of material in chemical solution, and the area of land surface drained by the rivers, that an average of 100 tons of rocky matter is dissolved per English square mile per annum. Of this he says: "If

* Brit. Assoc. Adv. Sci., sixty-second meeting, 1892, p. 21.

† *Proc. Liverpool Geol. Soc.*, 1877, vol. III, pt. 3, pp. 212–235. *Chemical Denudation in relation to Geological Time*, 1879, pp. 1–61.

we allot 50 tons to carbonate of lime, 20 tons to sulphate of lime, 7 to silica, 1 to carbonate of magnesia, 4 to sulphate of magnesia, 1 to peroxide of iron, 8 to chloride of sodium, and 6 to the alkaline carbonates and sulphates, we shall probably be as near the truth as present data will allow us to come."* By the use of the data given by Mr. John Murray, in a paper on the total annual rainfall on the land of the globe and the relation of rainfall to the discharge of rivers,† I obtain 113 tons as the total amount of matter in solution discharged into the Atlantic basin per annum from each square mile of area drained into it. Of this, 49 tons consist of carbonate of lime and 5·5 tons of sulphate and phosphate of lime.‡

Mechanical sediments.—With the geographic conditions described as prevailing during Paleozoic time, the source of mechanical sediments later than the Middle Cambrian must have been from the broken area on the eastern side that extended 100 to 200 miles to the eastward and to a much greater extent from the land along the western side of the sea. The enormous deposit of from 10,000 to 20,000 feet of mechanical sediments in early Cambrian time is explained by the assumption of favorable topographic conditions of denudation following the Algonkian revolution and the presence of a land area over the interior portion of the continent, and also, in all probability, between the western side of the Cordilleran sea and the western border of the continent. During this period the conformable pre-fossiliferous strata of the Cambrian accumulated, and about 6,000 feet of the lower fossiliferous rocks as they occur in the Eureka district of central Nevada. Following the depression of the continent, which carried down the central area and also introduced the Upper Cambrian (Mississippian) sea into the Rocky Mountain area of Colorado, etc., there were deposited of mechanical sediments in central Nevada:

	Feet.
Ordovician sands	500
Devonian fine argillaceous muds	2,000
Lower Carboniferous sands	3,000
Upper Carboniferous conglomerate and sands	2,000
	7,500

making a total of 7,500 feet of mechanical sediments, the remaining portion of the section (15,150 feet) being limestone.

The following table exhibits the relative thickness of mechanical and chemical deposits in the Cordilleran sea after the Middle Cambrian subsidence:

* *Proc. Liverpool Geolog. Soc.*, 1877, vol. III, p. 229.

† *Scottish Geol. Mag.*, 1887, vol. III, pp. 65–77.

‡ Total amount removed in solution per annum by rivers, 762,587 tons per cubic mile of river water. Total discharge of river water per annum into the Atlantic, 3,947 cubic miles. Area drained, 26,400,000 square miles. Amount of carbonate of lime per annum, 326,710 tons per cubic mile of river water; of sulphate and phosphate of lime, 37,274 tons.

	Wasatch.	Central Nevada.	Southwest Nevada.	Montana.	Alberta.
Mechanical sediment	10,000	7,500	2,500	1,000	4,600
Chemical sediment	10,400	15,150	13,000	4,000	15,000
Ratio	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$

If an average is taken of the mechanical sediment deposited subsequent to the close of Middle Cambrian time, it will be found to be about 5,000 feet for the entire area, which, I think, does away with any necessity for assuming an additional hypothetical land area for the source of the mechanical sediment. The fine sand composing the quartzites and the silt forming the shales, as well as the fine conglomerate of later deposits, were derived from the adjoining land areas, and, in all probability, currents swept through from the ocean to the south or north, distributing the mud and sand contributed from the rivers and streams along the shores.

Chemical sediments.—The present supply of the carbonate of lime, silica, etc., contained in sea water is derived from waters poured into the sea by rivers and streams. The Cordilleran sea undoubtedly received a large contribution from the adjoining land areas, but a considerable amount was possibly derived from an oceanic current that circulated through it, as the southern equatorial current of the Atlantic now sweeps through the Caribbean. From the vast deposits of carbonate of lime it might be assumed, *a priori*, that the waters of a Mississippi or Amazon were poured into it, but there is not any evidence of the existence of such a river, although the tributary area may have been very large in Cambrian and Carboniferous time if the drainage of the country west of Hudson Bay was to the westward.

Conditions of deposition.—With free communication into the open ocean on the south, and probably on the north, during most of Paleozoic time strong currents must have circulated through the Cordilleran sea. The broad distribution of mechanical sediments of a uniform character clearly shows this to have been the case, especially in pre-Silurian time. The present known distribution of the mechanical sediments indicates that they were mainly brought into the sea from the west,* although a vast amount was derived from the land on the eastern side in pre-Ordovician time; they were quite evenly distributed over the sea bed, except where local accumulations of silt and sand occurred near the larger sources of supply, or in the direction of powerful currents within the sea.

The conditions of the deposition of the carbonate of lime are less clearly understood than those governing mechanical sediments, and I shall enter upon the discussion of them at considerable length. There are three methods by which it is usually considered it may be depos-

* *Geol. Expl. Fortieth Parallel*, 1878, vol. I, p. 247.

ited: (1) agency of organisms; (2) chemical precipitation; (3) mechanical methods.

It is the general opionion of geologists that limestone rocks are the result almost entirely of the consolidation of lime removed from the sea water through the agency of life, and that they consist of the remains of foraminifera, crinoids, corals, etc., or their fragments, embedded in a more or less crystalline matrix resulting from subsequent alteration of the original deposits. This, however, has been seriously questioned. Sorby, in giving his general conclusions of an extensive microscopic examination of limestones, states that—

"Even if it were possible to study in a detached state the finer granular particles which constitute so large a part of many limestone formations, it would usually be impossible to say whether they had been derived from organisms which can decay down into granules, or from other organisms which can only be worn down into granules, or from ground down older limestone, or, in some cases, from carbonate of lime deposited chemically as granules. - - - The shape and character of the identifiable fragments do, indeed, *prove* that much of this must have been derived from the decayed and worn-down calcareous organisms; and very often we may reasonably *infer* that the greater part, if not the whole, was so derived; but at the same time it is impossible to *prove*, from the structure of the rock, whether some or how much was derived from limestones of earlier date, or was deposited chemically, as some certainly must have been."*

In their memoir on coral reefs and other carbonate-of-lime formations in modern seas, Messrs. Murray and Irvine show that temperature of the water has a controlling influence upon the abundance of species and individuals of lime-secreting organisms; high temperature is more favorable to abundant secretion of carbonate of lime than high salinity. †

Taking the samples of deep-sea deposits collected by the *Challenger* as a guide, the average percentage of carbonate of lime in the whole of the deposit covering the floor of the ocean is 36·83; of this it is estimated that fully 90 per cent is derived from pelagic organisms that have fallen from the surface water, the remainder of the carbonate of lime having been secreted by organisms that lay on, or were attached to, the bottom. The estimated area of the various kinds of deposits, the average depth, and the average percentage of carbonate of lime to each are shown in the following table:

* *Quart. Jour. Geol. Soc.*, London, 1879, vol. XXXV, pp. 91–92.

† *Proc. Royal Soc.*, Edinburgh, 1890, vol. XVII, p. 81.

Table showing the estimated area, mean depth, and mean percentage of $CaCO_3$ of the different deposits. *

Deposit.		Area, square miles.	Mean depth in fathoms.	Mean per cent of $CaCO_3$.
Oceanic oozes and clays.	Red clay	50, 289, 600	2, 727	6·70
	Radiolarian ooze	2, 790, 400	2, 894	4·01
	Diatom ooze	10, 420, 600	1, 477	22·96
	Globigerina ooze	47, 752, 500	1, 996	64·53
	Pteropod	887, 100	1, 118	79·26
Terrigenous deposits	Coral sands and muds	3, 219, 800	710	86·4
	Other terrigenous deposits, blue muds, etc	27. 899, 300	1, 016	19·20

"We have little knowledge as to the thickness of these deposits; still such as we have goes to show that in these organic calcareous oozes and muds we have a vast formation greatly exceeding in bulk and extent the coral reefs of tropical seas. They are most widely distributed in equatorial regions, but some patches of Globigerina ooze are to be found even within the Arctic circle, in the course of the Gulf Stream."†

The percentage of carbonate of lime contained in deposits accumulating at different depths, as obtained from 231 samples collected by the *Challenger*, is shown in the following tabulation:

14 cases under 500 fathoms, m. p. c	86·04
7 cases under 500 to 1000 fathoms, m. p. c	66·86
24 cases under 1000 to 1500 fathoms, m. p. c	70·87
42 cases under 1500 to 2000 fathoms, m. p. c	69·55
68 cases under 2000 to 2500 fathoms, m. p. c	46·73
65 cases under 2500 to 3000 fathoms, m. p. c	17·36
8 cases under 3000 to 3500 fathoms, m. p. c	·88
2 cases under 3500 to 4000 fathoms, m. p. c	0·00
1 case under 4000 fathoms, m. p. c	Trace.

The 14 samples under 500 fathoms are chiefly coral muds and sands, and the 7 samples from 500 to 1,000 fathoms contain a considerable quantity of mineral particles from continents or volcanic islands. In all the depths greater than 1,000 fathoms the carbonate of lime is mostly derived from the shells of pelagic organisms that have fallen from the surface waters, and it will be noticed that these wholly disappear from the greater depths.‡

By a series of experiments Messrs. Murray and Irvine found, "that although sea water under certain conditions may take up a considerable quantity of carbonate of lime in solution, yet it is unable permanently to retain in solution more than is usually found to be present in sea water, and it is owing to this that the amount of carbonate of lime is so constantly low. The reaction between organic matter and the sulphates present in sea water (to which we have referred) tends also to keep the amount of carbonate of lime in solution at about one half (0·12 grams) of what it might contain (0·28 grams per liter). This pecu-

* *Loc. cit.*, p. 82. † *Loc. cit.*, pp. 82, 83. ‡ *Loc. cit.*, p. 84.

liarity of sea water in taking up a large amount of amorphous carbonate of lime and throwing it out in crystalline form accounts for the filling up of the interstices of massive coral with crystalline carbonate in coral islands and other calcareous formations, so that all traces may ultimately be lost of the original organic structures.*

The authors explain the disappearance of shells and lime deposits in the greater depths of the ocean by their being dissolved by the carbonic acid in the water, which is present in larger quantity at great depths, and also is produced by the decomposition of the animal matter of the shell and of the various organisms living in the water and on the bottom. They conclude that—

"On the whole, however, the quantity of carbonate of lime that is secreted by animals must exceed what is redissolved by the action of sea water, and at the present time there is a vast accumulation of the carbonate of lime going on in the ocean. It has been the same in the past, for with a few insignificant exceptions all the carbonate of lime in the geological series of rocks has been secreted from sea water and owes its origin to organisms in the same way as the carbon of the carboniferous formations; the extent of these deposits appears to have been increased from the earliest down to the present geological period."†

In their report on deep sea deposits, collected by the *Challenger* expedition, Messrs. Murray and Renard state that the chemical products formed *in situ* on the floor of the ocean nearly all originate in a sort of broth or ooze, in which the sea water is but slowly renewed. Many of them appear to be formed at the surface of the deposit—at the line separating the ooze from the superincumbent water, where oxidation takes place. In the deeper layers of the deposit a reduction of the higher oxides frequently occurs, and at the surface of the mud or ooze there are many living animals as well as the dead remains of surface plants and animals.‡ They also conclude that practically all the carbon of marine organisms must ultimately be resolved into carbonic acid. The quantity of that acid produced in this way must be enormous, and can not but exert a great solvent action not only on the dead calcareous structure, but also on the minerals in the muds on the floor of the ocean.§ Of the effect of this destructive action they say: "In all cases, however, calcareous structures of all kinds are slowly removed from the bottom of the ocean on the death of the organisms, unless rapidly covered up by the accumulating deposits, and in this way protected to a certain extent from the solvent action of the sea water. It is evident from the *Challenger* investigations that whole classes of animals with hard, calcareous shells and skeletons, remains of which one might suppose would be preserved in modern deposits, are not there repre-

* *Loc. cit.*, pp. 94–95.

† *Loc. cit.*, p. 100.

‡ Report on the Scientific Results of the Voyage of H. M. S. *Challenger*. Deep-Sea Deposits. 1891, p. 337.

§ *Loc. cit.*, p. 255.

sented; although they are now living in immense numbers in the surface waters or on the deposits at the bottom in some regions, yet all traces of them have been removed by solution. A similar removal of calcareous organic structures has undoubtedly taken place in the marine formations of past geological ages."*

From the preceding statements it is evident that initially the greater part of the carbonate of lime is taken from the sea water by organic agency, but in the working over of this material in the chemical laboratory at the bottom of the sea a considerable portion is taken up by the sea water as amorphous carbonate of lime and thrown out in the crystalline form to form the matrix of the undissolved shells, etc.†

Mr. Bailey Willis has recently studied the question of the deposition of carbonate of lime, and states that "chemists describe two conditions under which bicarbonate of lime may be decomposed into neutral carbonate and carbonic acid: first, by diminution of the tension of the carbonic acid in the atmosphere; second, by agitation of the solution.

"Theoretically either one of three things may occur to the neutral carbonate of lime, if it be thrown out of solution by either one of these processes. The carbonate may be redissolved, deposited as a calcareous mud, or built into organic structures." He studied some recent limestone deposited in the Everglades of southern Florida and found it to be formed of fragments of shells embedded in calcite. He states that "under the microscope the unaltered structure of the organic fragments is strikingly different from that of the coarse holocrystalline matrix, in which it is apparent that the crystals developed in place. Were this a limestone of some past geologic period it would be concluded, on the evidence of the crystalline texture of some parts of it, that it had been metamorphosed and that the organic remains now visible had escaped the process which altered the matrix. But the observed conditions of its formation preclude the hypothesis of secondary crystallization."‡ Apparently the crystalline matrix is one primary product, and the calcareous mud is another, which being precipitated in the solution remains an incoherent sediment.

I think we may accept the conclusion that the deposition of carbonate of lime is by both organic agency and chemical precipitation. It is not necessary to speak of deposition by mechanical methods except in relation to the deposition of chemically derived granules. This probably takes place, and may be a very important factor in the formation of limestones in seas receiving a large supply of calcium from the land. Calcareous conglomerates do not enter as a prominent deposit in the Cordilleran area.

* *Loc. cit.*, p. 277. In this connection I wish to ask the student to read Messrs. Murray and Irvine's remarks on pp. 97–99, *Proc. Royal Soc. Edinburgh*, 1890, vol. XVII.

† *Proc. Royal Soc. Edinburgh*, 1890, vol. XVII, pp. 94, 95.

‡ See Mr. Willis's article in *Journal of Geology*, Chicago, July–August, 1893.

There is no evidence in the marine geologic formations of this continent that they were deposited in the deep sea; on the contrary, they are unlike such deposits and bear positive evidence of having been laid down in relatively shallow waters. Limestones with ripple marks and sun cracks occur, and beds of ripple-marked sandstones alternate with shales and limestones. The more massive limestones, however, appear to have accumulated in deeper water. The conditions in the Cordilleran sea were, I think, more favorable for rapid deposition than in the deep open ocean, but probably not as favorable as about coral reefs and islands. The limestones and often the contained fossils clearly indicate the presence of many of the same conditions of deposition as described by the authors I have quoted. More or less decomposed shells occur in nearly every limestone; and a large proportion of limestones, especially the nonmetamorphic marbles, clearly shows that they were deposited under the influence of the agencies at work in the laboratory of the sea. Willis states that this occurs in the shallow waters of the Everglades of Florida, and there is no *a priori* reason why it did not occur throughout geologic time; on the contrary, there is no doubt that it did.

Rate of deposit in former times.—It has frequently been assumed that in the earlier epochs the conditions were more favorable for rapid denudation and in consequence thereof the transportation and deposition of sediment were greater. Prof. Prestwich considers* that prior to the sedimentary rocks the land surface consisted of crystalline or igneous rocks subject to rapid decomposition owing to the composition of the atmosphere and to their inherent tendency to decay. They must have yielded to wear and removal with a facility unknown amongst mechanically-formed and detrital strata where erosion operates. He thus accounts for one of the factors that gave the large dimensions and thicknesses of the earlier formations. Mr. Wallace thinks that geological change was probably greater in very remote times,† stating that all telluric action increases as we go back into the past time and that all the forces that have brought about geological phenomena were greater.‡

Dr. Woodward says on the opposite view, that in the earliest geological periods each bed of sand, clay, limestone, etc., had actually to be formed, and that later deposits had the older sedimentary ones to furnish

* *Geology*, 1886, vol. I, pp. 60, 61.

† *Island Life*, 2d ed., 1892, pp. 223–224.

‡ Sir William Thomson (Lord Kelvin) inferred from his investigations upon the cooling of the earth, that the general climate can not be sensibly affected by conducted heat at any time more than 10 000 years after the commencement of superficial solidification. *Treatise on Natural Philosophy*, Cambridge, 1883, vol. 1, pt. 2, p. 478.

Of the degree of the sun's heat we know so little that conjectures in relation to it have little force against the conditions indicated by the sedimentary rocks and their contained organic remains.

material, and therefore the newer deposits were laid down more rapidly.* This does not impress me strongly; but from my experience among the Paleozoic rocks I agree with Sir A. Geikie, that "we can see no proof whatever, nor even any evidence which suggests—that on the whole the rate of waste and sedimentation was more rapid during Mesozoic and Paleozoic time than it is to-day."†

Prof. Huxley, in his presidential address to the Geological Society of London in 1870, treats of the distribution of animals, and says of his hypothesis that it "requires no supposition that the rate of change in organic life has been either greater or less in ancient times than it is now; nor any assumption, either physical or biological, which has not its justification in analogous phenomena of existing nature."‡

In the Grand Canyon of the Colorado, Arizona, there are 11,950 feet of strata of Algonkian age extending uncomformably beneath the Cambrian. There is nothing in this section to indicate that the conditions of deposition were unlike those of the strata of Paleozoic and Mesozoic time. The sandstones, shales, and limestones are identical in appearance and characteristics with those of the latter epoch. The deposition of sulphate of lime and gypsum occurred abundantly in the upper portions of the series, and salt is collected by the Indians from the deposits formed by the saline waters issuing from the sandstone 8,000 feet below the summit of the series. The sandstones and shales were deposited in thin, even laminæ and layers, and the sun cracks and ripple marks give evidence of slow, uniform deposition. In the upper or Chuar terrane, there are 235 feet of limestone. And in one of the layers of limestone, 2,700 feet below the summit of the Chuar terrane, I find abundant evidence of the presence of spiculæ of sponges and what appear to be worn fragments of some small fossils. There is absolutely nothing to indicate more rapid denudation and corresponding deposition in this early pre-Cambrian series than we find in the Paleozoic, Mesozoic, or Cenozoic formations.

PALEOZOIC SEDIMENTS OF THE CORDILLERAN SEA.

The great sections of sedimentary rocks in Arizona, Nevada, Utah, Montana, and in Alberta, British America, all bear evidence that the sediments of which they are built up were deposited in a connected and continuous sea that extended from the vicinity of the thirty-fourth parallel, on the south, to the Arctic Ocean on the north. Judging from the data now available the width of this sea varies from 300 miles in Nevada to 500 miles on the line of the fortieth parallel, and, with interruptions by mountain ridges, to 250 miles on the forty-ninth parallel. It appears to have narrowed to the north in Alberta and British Colum-

* *Geol. England and Wales*, 2d ed., 1887, p. 23.

† *Rept. Sixty-second Meeting Brit. Assoc. Adv. Sci.*, 1892, p. 19.

‡ *Quart. Jour. Geol. Soc.*, 1870, vol. XXVI, p. lxiii.

bia. Roughly computed, it covered, south of the fifty-fifth parallel, 400,000 square miles, exclusive of any extension westward into northern-central California and southwestern Oregon and to the eastward over the area subsequently covered by the great interior Cretaceous sea. There is also an addition that might be made to allow for the contraction of the area by the later north-and-south faults and thrusts. Dr. G. M. Dawson estimates that in the Alberta and British Columbia area the width of the zone of Paleozoic rocks has probably been reduced one-half by the folding and faulting, or from 200 to 100 miles.* The area assumed for the Cordilleran Sea is on this account probably one-half less than it was before the close of the Appalachian revolution.

The Wasatch section, on the eastern side of the area under consideration, has 30,000 feet of strata, of which 10,400 feet are limestone.† Further to the west, 250 miles west-southwest, at Eureka, Nev., there are 30,000 feet of strata in the entire section, and of this amount 19,000 feet are referred to limestone.‡ In the Pahranagat range and vicinity, 200 miles south of the Eureka section,§ the limestones of the Paleozoic measure over 13,000 feet in a section of 15,500 feet. This section includes only 350 feet of the upper beds of the lower quartzite series, which is upwards of 11,000 feet in thickness in the Schell Creek range of eastern Nevada.||

On the eastern side of the area, in Montana, 300 miles north of the Wasatch section of Utah, the deposit of Paleozoic sediment is less in volume. Dr. A. C. Peale's section gives 3,800 feet of limestone in 5,000 feet of strata.¶ This does not include the 6,000 feet or more of sediments that occur below the fossiliferous Cambrian. I believe that the Paleozoic section will be found to be considerably thicker to the westward, in Idaho. Continuing to the north 450 miles, the sections measured by Mr. R. G. McConnell give 29,000 feet of Paleozoic strata, including 14,000 feet of limestones.** In a "Note on the Geological Structure of the Selkirk Range," Dr. Geo. M. Dawson describes a section containing upwards of 40,000 feet of mechanical sediments, which he refers largely to the Cambrian.††

The Paleozoic limestones extend to the north, on the line of the eastern Rocky Mountains, to the Arctic Ocean. In latitude 55° to 60° north, the Devonian limestones are over 2,500 feet in thickness, and there are other still lower Paleozoic rocks that have not yet been studied in detail. The Devonian limestones extend 700 miles in the valley of the Mackenzie, from Great Slave Lake to below Fort Good

* *Bull. Geol. Soc. Am.*, 1891, vol. II, p. 176.

† *Geol. Expl. Fortieth Parallel*, 1878, vol. I, pp. 155–156.

‡ *Mon. U. S. Geol. Survey*, 1892, vol. XX, p. 178.

§ *Loc. cit.*, pp. 186–200.

|| *Geol. and Geog. Surveys west of 100th Merid.*, vol. III; 1875, Geology, p. 167.

¶ Author's manuscript.

** *Geol. and Nat. Hist. Sur., Can.;* Ann. Rep., 1886, pp. 17D-30D.

†† *Bull. Geol. Soc. Am.*, 1891, vol. II, p. 168.

Hope.* No Carboniferous limestones have been described from this region.

Tabulating the sections south from the Fifty-fifth parallel and allowing for a great thinning out of the sediments in Idaho and Montana, we obtain an approximate general average of 21,000 feet of strata, of which 6,000 feet are limestone over an area estimated to include 400,000 square miles. Each square mile includes 27,878,400 cubic feet of limestone for each foot in thickness, and 167,270,400,000 cubic feet for a thickness of 6,000 feet, which, with an average of 12·5 cubic feet to the ton, gives 13,381,632,000 tons of limestone and impurities per square mile. The result of 10 analyses of clear limestones within the central portion of the area gives an average of 76·5 per cent of carbonate of lime.† Taking 75 per cent as the proportion of pure carbonate of lime (after deducting 50 per cent to allow for arenaceous and argillaceous material in partings of strata, etc.), there remain 5,018,112,000 tons per square mile; multiplying this by 400,000 the result gives the number of tons of carbonate of lime that were deposited in what we know of the Cordilleran sea in Paleozoic time—or 2,007,244,800,000,000 tons, or two thousand trillion tons in round numbers.

The following mode of presentation of the above was suggested by Mr. Willis:

"In order to proceed with a calculation of the period required to form this thickness of 15,000 feet of mechanical sediment plus 6,000 feet of calcareous sediment, it is necessary, first, to compute the cubic volumes of the sediments; second, to estimate the area from which they were derived; and, third, to divide the cubic contents of the sediments by this land area. The result thus obtained represents the depth of erosion required to furnish the whole deposit, from which we may estimate the time under different assumptions of the rate of erosion.

"But if we express amounts in cubic feet or tons the figures pass all comprehension; therefore to simplify the statement it is well to use a mile-foot as a unit of volume, that is, the volume of 1 mile square and 1 foot thick. (1 mile-foot=0.79 kilometer-meter.) This is equal to 223,000 tons, if 12½ cubic feet of limestone equal 1 ton.

"Thus stated, mechanical sediments covering 400,000 square miles and 15,000 feet thick contain 6,000,000,000 mile-feet (4,740,000,000 kilometer-meters); and calcareous sediments covering the same area and 6,000 feet thick correspond to 2,400,000,000 mile-feet (1,896,000,000 kilometer-meters). In the calcareous sediments a liberal allowance of one-half may be made for arenaceous and argillaceous matter in the limestone and partings, and analyses of 10 clear limestones within the central part of the area give a little more than 75 per cent of carbonate of lime. Applying these reductions we get 900,000,000 mile-feet (711,000,000 kilometer-meters) of pure carbonate of lime."

DURATION OF PALEOZOIC TIME IN THE CORDILLERAN AREA.

Estimates from mechanical sedimentation.—The land area tributary to the Cordilleran sea was larger before the depression of the continent,

* *Rept. Expl. Yukon and Mackenzie rivers Basins, N. W., Terr., Geol. and Nat. Hist. Sur. Canada,* (1888–89) 1890, vol. IV, pp. 13D-18D.

†*Geol. Expl. Fortieth Par.*, vol. II; Mon. U. S. Geol. Survey, vol. XX,

towards the close of middle Cambrian time, than during subsequent Paleozoic time. It included a portion of the region to the eastward and probably a belt of land extending well toward the Pacific coast of the continental plateau. The interior (Mississippian) region, west of the ninetieth meridian, probably drained into the sea to the south, forming a Cambrian Mississippi river prior to middle Cambrian time. This limits the Cambrian drainage into the Cordilleran sea to an area estimated at 1,600,000 square miles. The average thickness of mechanical sediments deposited before upper Cambrian time is estimated at from 10,000 to 15,000 feet. Taking the minimum of 10,000 feet and the assumed drainage area of 1,600,000 square miles and the rate of denudation at 1 foot in 1,000 years, it would have required 2,500,000 years to carry to the sea and distribute the 10,000 feet of sediment. This means the deposition of 0·048 of an inch per year, which is very small if the supposed conditions of denudation and transportation were as favorable as the character and mode of occurrence of the sediments indicate. If one-fourth of an inch per year is assumed as the rate of deposition, the 10,000 feet of sediment would have accumulated in 480,000 years or, in round numbers, in 500,000 years, which increases the rate of denudation to 1 foot in 200 years.*

In dealing with the post-middle Cambrian mechanical sediments we have a somewhat different problem, but, as a whole, rapid deposition is indicated. For instance, the Eureka quartzite of the upper Ordovician is a bed of sandstone, varying from 200 to 400 feet in thickness. distributed over a wide area, perhaps 50,000 square miles. It is made almost entirely of a white, clean sand that was deposited in so short an interval that the Trenton fauna in the limestone beneath it and in the limestones above it is essentially the same. The sand appears to have been swept rapidly into the sea and distributed by strong currents. The same is true of the 3,000 feet of the lower Carboniferous

* By Mr. Willis' method (*ante*, p. 323) the mechanical sediments of the Paleozoic age for the area under consideration correspond to 6,000,000,000 mile-feet. Of this total the greater part, namely, two-thirds or 4,000,000,000 mile-feet, are of Cambrian age. Dividing this volume by the land area just given, 1,600,000 square miles, we get 2,500 feet as the depth of erosion during the formation of the Cambrian mechanical sediments. Assuming different rates of erosion we may obtain times differing as follows:

Cambrian mechanical sediments.

Rate of erosion over land area of 1,600 000 square miles.	Time in years for erosion of 2 500 feet.	Rate of deposition over sea area of 400 000 square miles for strata 10 000 feet thick.
1 foot in 3,000 years	7,500,000	1 foot in 750 years, or 0·016-inch per annum.
1 foot in 1,000 years	2,500,000	1 foot in 250 years, or 0·048-inch per annum.
1 foot in 200 years	500,000	1 foot in 50 years, or 0·24-inch per annum.

In view of the evidence of rapid accumulation contained in the strata themselves the most rapid rate of deposition here stated, namely, 0·24-inch per annum, is considered as the most probable.

sand and the 2,000 feet in the upper portion of the Carboniferous, while the shales of the upper Devonian accumulated more slowly. In this connection we must bear in mind that during the long periods in which the calcareous sediments forming the limestones were being deposited, the tributary land areas were, in all probability, base levels of erosion, and chemical denudation was preparing a great supply of mechanical material that, on the raising of the land, was rapidly swept into the sea and distributed. In this manner the time period of actual mechanical denudation was materially shortened, yet, on account of the manifestly slower depositions of the Devonian shales, the rate of denudation should be assumed as less than during Cambrian time.

In post-Cambrian time the area of the land surface was materially reduced by subsidence, which did not, however, greatly extend the Cordilleran sea, and it may fairly be estimated at 600,000 square miles. The depth of mechanical sediments already estimated is 5,000 feet and their volume 2,000,000,000 mile-feet. Dividing the volume by the area of erosion we get 3,300 feet as the depth of erosion required.

Again, applying different rates of erosion with allowance for slow progress of degradation during Devonian time, we have:

Post-Cambrian mechanical sediments.

Rate of erosion over land area of 600,000 square miles.	Time required for removal of 3 300 feet.	Rate of deposition in sea of 400,000 square miles, for 5,000 feet of strata.
1 foot in 3,000 years	9,900,000 years	1 foot in 1,980 years, or 0.006 inch per annum.
1 foot in 1,000 years	3,300,000 years	1 foot in 660 years, or 0.018 inch per annum.
1 foot in 200 years	660,000 years	1 foot in 132 years, or 0.09 inch per annum.

The rate of 1 foot in 200 years is assumed as the most probable and 660,000 years as the time required for the removal and deposition of the 5,000 feet of post-Cambrian mechanical sediments.

There is one factor that may need to be taken into consideration in estimating the time duration of the deposition of the mechanical sediments of the Cambrian and pre(?)-Cambrian of the northern portion of the Cordilleran sea that would materially lengthen the period. Dr. George M. Dawson describes the Nisconlith series, especially in the Selkirk range of British Columbia, as composed of "blackish argillite-schists and phyllites, generally calcareous with some beds of limestone and quartzite, 15,000 feet."* It is correlated with the Bow River series, which contains, in the upper portion, the lower Cambrian fauna. The presence of these calcareous beds indicates a slower rate of deposition than we have estimated for the lower portion of the Cambrian

* *Bull. Geol. Soc. Am.*, 1891, vol., II, p. 168.

series over the greater part of the Cordilleran sea; but as yet the correlation with the sediments of the Cordilleran sea is not sufficiently well established to warrant our allowing a greater time period to the Cambrian on this account.

Estimates from chemical sedimentation.—We have estimated that the Paleozoic sediments of the Cordilleran sea contain 2,007,244,800,000,000 [2 thousand trillion] tons (900,000,000 mile-feet) of carbonate of lime which was derived by organic or chemical agencies from the sea water to which it was contributed by the land. If oceanic circulation could be excluded from the problem we might proceed directly to estimate the time required to obtain this amount of lime from the land area tributary to the Cordilleran sea. It may be well to make such an estimate on the basis that the area of denudation tributary to the Cordilleran sea in post-middle Cambrian time had 600,000 square miles, from which 30,000,000 tons of carbonate of lime and 12,000,000 tons of sulphate of lime were derived per annum* if we assume T. Mellard Reade's rate of erosion—of 50 tons of carbonate of lime and 20 tons of sulphate of lime per square mile per annum. If all of the 42,000,000 tons (equal to 18·8 mile-feet) per annum were deposited within the limits of the Cordilleran sea, it would have taken 47,790,000 years for the accumulation of the carbonate of lime now estimated to have been deposited in the Cardilleran sea. Such a result is manifestly a maximum, based on the consideration of one set of phenomena. In addition, however, to this supply of calcium the geographic conditions appear to have been favorable to the free circulation of oceanic currents through the Cordilleran sea, and the temperature was favorable to extensive evaporation and to the development of organic life, as shown by the occurrence of corals in the Middle and Upper portions of the Paleozoic, from the Mackenzie River basin on the north to southern Nevada on the south. These conditions would reduce the time necessary for the deposition of the carbonate of lime.

Ocean water of the present time contains in solution 151,025,000 tons of solid matter per cubic mile, which is divided among various salts. A comparison of the matter in the sea and river water shows that the sea contains 3.85 parts of magnesium to 1 of calcium, and river water contains 3 parts of calcium to 1 of magnesium. The silica and alumina of the river water disappear in sea water, while the sodium is accumulated. It is from these considerations and the fact that limestones are so largely formed of carbonate of lime that I have taken the latter as a basis for estimates upon the rate of chemical sedimentation, an allowance being made for the presence of silica, alumina, and magnesium in the limestones.

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*Messrs. Murray and Renard consider that organisms have the power of secreting the carbonate of lime from the sulphate of lime contained in the sea water by chemical reaction. For an account of the chemical action that takes place in the sea water see report of the Deep-sea Deposits of the *Challenger* Expedition.

Rate of deposition in recent deposits.—Of the rate of deposition in recent deposits Messrs. Murray and Renard state, in their report on the deep-sea deposits, that—

"It must be admitted that at the present time we have no definite knowledge as to the absolute rate of accumulation of any deep-sea deposit, although we have some information and some indications as to the relative rate of accumulation of the different types of deposits among themselves. The most rapid accumulation appears to take place in the terrigenous deposits, and especially in the Blue Muds, not far removed from the embouchures of large rivers. Here no great time would seem to have elapsed since the deposit was formed, so far at least as the materials collected by the dredge, trawl, and sounding tube are concerned.

"Around some coral reefs the accumulation must be rapid, for, although pelagic species with calcareous shells may be numerous in the surface waters, it is often impossible to detect more than an occasional pelagic shell among the other calcareous débris of the deposits.

"The pelagic deposits as a whole, having regard to the nature and condition of their organic and mineralogical constituents, evidently accumulate at a much slower rate than the terrigenous deposits, in which the materials washed down from the land play so large a part. The Pteropod and Globigerina oozes of the tropical regions, being chiefly made up of the calcareous shells of a much larger number of tropical species, must necessarily accumulate at a greater rate than the Globigerina oozes in extra-tropical areas or other organic oozes. Diatom ooze, being composed of both calcareous and siliceous organisms, has, again, a more rapid rate of deposition than the Radiolarian ooze, while in a Red Clay there is a minimum rate of growth."*

Prof. James D. Dana estimates that the rate of increase of coral reef limestone formations, where all is most favorable, does not exceed perhaps a sixteenth of an inch a year, or 5 feet in 1 000 years. Of this he says: "And yet such limestones probably form at a more rapid rate than those made of shells."†

Messrs. Murray and Irvine, in their valuable paper on coral reefs and other carbonate of lime formations in modern seas, calculate the total amount of calcium in the whole ocean to be 628,340,000,000,000 [628 trillion] tons; also they estimate that 925,866,500 tons of calcium are carried into the ocean from all the rivers of the globe annually. At this rate it would take 680,000 years for the river drainage from the land to carry down an amount of calcium equal to that at present existing in solution in the whole ocean. They say further: "Again, taking the *Challenger* deposits as a guide, the amount of calcium in these deposits, if they be 22 feet thick, is equal to the total amount of calcium in solution in the whole ocean at the present time. It follows from this that if the salinity of the ocean has remained the same as at the present during the whole of this period, then it has taken 680,000 years for the deposits of the above thickness, or containing calcium in amount equal to that

***Report on the scientific results of the voyage of H. M. S. Challenger; Deep-Sea Deposits.* 1891, pp. 411-412.

†*Corals and Coral Islands,* 3d ed., 1890, pp. 396, 397.

at present in solution in the ocean, to have accumulated on the floor of the ocean."* According to this calculation the mean rate of accumulation over existing oceanic areas is $\frac{22}{680000}$ or 0·000032 feet per annum.

Was deposition of chemical sediments more rapid during Paleozoic time?—It has been claimed that the quantity of lime poured into the ocean in earlier times was greater than during the later epochs of geological history, this arising from the more rapid disintegration of the Archean, crystalline, and volcanic rocks. It is undoubtedly a fact that the ocean was stocked in Archean and Algonkian times with matter in solution that produced salinity, but we have no evidence from chemical precipitation that more calcium was poured into it than could be retained in solution. The Laurentian limestones are crystalline, but, as has been shown, this texture is consistent with either chemical or organic origin. The unaltered limestones of the Algonkian rocks of the Colorado canyon section show traces of life in thin sections, and they may, to a great extent, be of organic origin. There is no evidence in the texture, bedding, or composition of ancient limestones to indicate that they were deposited under conditions of salinity or of supply differing materially from those of the present, and I do not find that we have reason to believe that the deposition of the carbonate of lime was more rapid in the Paleozoic than during the Mesozoic and Cenozoic times, even though the supply from the land may have been greater. Where the conditions were favorable for the deposition of lime, as in the Cretaceous sea of northern Mexico, we find evidence of an immense accumulation of calcareous sediments. Of the amount of calcareous deposits in the seas outside of the continental areas that are not open to our inspection we know nothing, but judging from the deposition that is going on to day in the great oceans, the accumulation of calcareous sediment has gone on in the past as steadily and uninterruptedly as at present, subject to varying conditions of temperature, life, depth of water, etc.

Area of deposition in Paleozoic time.—We have no proof that the salinity of the sea or the amount of calcium contained in it has varied from age to age since Algonkian time. If it has not, all of the calcium poured into the ocean during 2,000,000 years would have about equaled the amount now contained in the limestones of the Cordilleran area. We have, however, to account for the calcium deposited in the interior Mississippian sea and the seas over other portions of this continent and other continental areas and on portions of the floor of the ocean that are not now accessible for observation. It is also to be considered that the land areas subject to denudation in Paleozoic time were, in all probability, of no larger extent than at the present time.

The area of dry land to-day is estimated to be 55,000,000 square miles, and of oceans 137,200,000 square miles.†

* *Proc. Royal Soc. Edinburgh*, 1890, vol. XVII, p. 101.

† Dr. John Murray, *Scottish Geog. Mag.*, 1888, vol. IV, p. 40.

Mr. T. Mellard Reade estimates the area of the Paleozoic formations of Europe at 615,600 square miles in the total area of 3,720,500 square miles. His estimate of the Paleozoic area is of that which is exposed at the present time and does not include that which is concealed beneath other formations. I think it will be a minimum estimate to consider that an equal area is covered by the later formations, which, with that exposed, would give in round numbers 1,290,000 square miles, or one-third of the land area of Europe. In North America nearly one-half of the total area was covered by the Paleozoic sea; in South America it was considerably less; and we know too little of the Asiatic and African continents to place any estimate upon their Paleozoic areas. I think, however, if we take one-fourth of the present land area as the territory covered by the Paleozoic seas we shall be considerably within the actual amount, even if we add to the surface of the continents the margins of the continental platforms now beneath the sea. Deducting the one-fourth from the total land area, there remain 41,250,000 square miles as the land area undergoing denudation during Paleozoic time. It may be claimed that large areas in the archipelago region of the Pacific and in the Arctic ocean may have been land areas at that time. To meet this, 8,750,000 square miles may be added to the 41,250,000 giving a total of 50,000,000 square miles as the land area of Paleozoic time.

The estimated areas of the various deep-sea deposits of to-day containing a large percentage of the carbonate of lime, are as follows: Globigerina ooze, 49,520,000 square miles, mean percentage of carbonate of lime, 64·53; Pteropod ooze, 400,000 square miles, percentage of carbonate of lime, 79·26; coral mud and sand, 2,556,000 square miles, mean percentage of carbonate of lime, 86·41. In addition to this, Diatom ooze covers an area of 10,880,000 square miles, with 22·96 percentage of carbonate of lime; and the mean percentage of carbonate of lime in the Blue Mud and other terrigenous deposits that cover 16,050,000 square miles is 19·20. If we consider only those deposits containing over 64 per cent of carbonate of lime, we have 52,500,000 square miles, over which there is at the present time a deposition of the carbonate of lime being made. We have roughly estimated that in Paleozoic time the area of the Paleozoic sea, in which deposits were being accumulated, was over 13,000,000 square miles. It does not appear that there is any good reason to suspect that the area of deposition of the carbonate of lime in the open ocean during Paleozoic time was not fully equal to that of the present time. Adding this area of 52,500,000 to the 13,750,000, we have over 66,000,000 square miles as the probable area in which calcium was being deposited in Paleozoic time.

Conditions favorable for a rapid deposition of the carbonate of lime.—The conditions most favorable for the rapid accumulation or deposition of the carbonate of lime through organic or chemical agency are warm water and a constant supply of water through circulation by currents.

This is shown by the immense abundance of life where the margin of the continental plateau is touched by the Gulf Stream. Another favorable condition is the supply of carbonate of lime by river water directly into the ocean in the vicinity where the deposition of lime is going on either through organic or inorganic agencies. This is well illustrated by the conditions produced by the Gulf Stream. The oceanic currents, passing along the northeastern coast of South America, sweep the waters of the Amazon through the Caribbean Sea into the Gulf of Mexico, where they meet the vast volume of water coming from the Mississippi. These are poured out through the narrow straits between Florida and Cuba and carried northward over the sloping margin of the continental plateau. Under such favorable conditions the deposit must be much greater than in areas where there is little circulation and the supply of calcium is limited to the average which is contained in sea water. If to the preceding there be added extensive evaporation within a partially inclosed sea, the rate of deposition of matter in solution will be largely increased.

Estimate from deposition of calcium derived from Cordilleran sea and the outer ocean, and from the deposition of mechanical sediments.—The area over which calcareous deposition was going on during Paleozoic time we have estimated at 66,000,000 square miles, which includes the areas of the seas over the continental platforms and those of the surrounding oceans. As the conditions appear to have been more favorable for the deposition of lime in the Cordilleran and Appalachian seas, we will assume that it was four times that of the open oceans.* With a land area of 50,000,000 square miles and a rate of chemical denudation of 70 tons per square mile per annum, the total calcium contributed to the ocean per year during Paleozoic time would be 3,500,000,000 tons, or 3·78 times as much as that estimated per annum at the present time, which is 925,866,500 tons. This would have provided 50·7 tons for deposition per annum per square mile in the 65,000,000 square miles of ocean and seas, and 202·8 tons for deposition per annum per square mile in the 400,000 square miles of the Cordilleran and 600,000 square miles of similar seas. On this basis 81,120,000 tons (36·4 mile-feet) were contributed per annum from the ocean water to the deposit in the Cordilleran sea; adding to this the 42,000,000 tons (18·8 mile-feet) contributed per annum by the denudation of the surrounding area to the Cordilleran sea, we have 123,120,000 tons (55·2 mile-feet) as the amount available

* Under the reduction of 50 per cent for the interbedded and intermingled mechanical sediments and 25 per cent for other material than calcium deposited from solution, the apparent amount of calcium deposited in the Cordilleran sea was greatly reduced. If this same ratio of reduction is applied to other Paleozoic limestone areas I doubt if over 1,000,000 square miles will be found to contain as large an average amount of calcium per square mile as the Cordilleran area. On this account 1,000,000 square miles is the area taken for the greater rate of deposition of calcium during Paleozoic time.

for deposit per annum in the Cordilleran sea. At this rate it would have required 16,300,000 years to have deposited the 2,007,244,800,000,000 [2 thousand trillion] tons (900,000,000 mile-feet) of *calcium* in the Cordilleran sea; adding to this the 1,200,000 years estimated for the deposition of the mechanical sediments, we have a total of 17,500,000 years as the duration of Paleozoic time.

In reviewing the preceding estimates we must consider that throughout I have increased the various factors above those usually accepted—thus for mechanical sedimentation the erosion of 1 foot in 200 years is used. If the usually accepted average of 1 foot in 3,000 years is taken the time period must be increased fifteen fold (21,000,000 years), or the area of denudation from 1,600,000 square miles to 24,000,000, or three times the present area of the North American Continent.

In the estimate for the amount of chemical denudation, the largest average is taken—70 tons of calcium per square mile per annum—and the assumption made that all calcium derived from the adjoining drainage area was deposited within the Cordilleran sea. Again, the total supply provided per annum to ocean waters of Paleozoic time is taken as 3·78 times greater than the amount annually contributed to ocean waters to-day; of this four times as much is assumed to have been taken out per annum per square mile in the Cordilleran sea as was taken by the remaining area in which calcium was being deposited.

The area of the Cordilleran sea is given as 400,000 square miles, but it was probably 600,000, if not much more. It may be claimed that the area tributary to the Cordilleran sea was greater than I have estimated. The evidence, such as it is, is against such a view. As a whole, I think the estimate of 17,500,000 years for the duration of Paleozoic time in the Cordilleran area is below the minimum rather than above it.

If the estimated rate of the deposition of coral limestones—5 feet in 1,000 years—given by Prof. James D. Dana is correct, the 19,000 feet of Paleozoic limestone in central Nevada would have required 3,800,000 years to have accumulated under the most favorable local conditions surrounding a coral reef. With the exception of large deposits of corals in Devonian rocks no appearance of a coral reef is recorded in the Cordilleran area.

TIME RATIOS OF GEOLOGIC PERIODS.

The time ratio adopted by Prof. James D. Dana for the Paleozoic, Mesozoic, and Cenozoic periods is, 12, 3, and 1, respectively.* Prof. Henry S. Williams applies the term *geochronology*, giving the standard time unit used the name *geochrone*. The geochrone used by him in obtaining a standard scale of geochronology is the period represented by the Eocene. His time scale gives 15 for the Paleozoic, 3 for the Mesozoic, and 1 for the Cenozoic, including the Quaternary and the Recent.†

* *Manual of Geology*, 1875, p. 586.

† *Journal of Geology*, Chicago, 1893, vol. I, pp. 294, 295.

The Rev. Samuel Houghton obtained the following time ratios from the maximum thickness of strata as they occur in Europe:

Scale of geological time.

Period.	From theory of cooling globe.	From maximum thickness of strata.
	Per cent.	*Per cent.*
Azoic	33·0	34·3
Paleozoic	41·0	42·5
Neozoic	26·0	23·2
Total	100·0	100·0

He draws from this the principle: "*The proper relative measure of geological periods is the maximum thickness of the strata formed during those periods.*"*

In considering the time ratios for the Paleozoic, Mesozoic, and Cenozoic rocks of the North American continent as given by Dana and Williams, I think that a too small proportion has been given to the Mesozoic and Cenozoic. In the Mesozoic of the western central area occur the coal deposits of the Laramie series and the great development of limestones (from 10,000 to 20,000 feet) in the Cretaceous of Mexico. The limits of this paper do not permit of a discussion of the available data bearing upon geologic time ratios; but from a comparison of the Paleozoic, Mesozoic, and Cenozoic strata and the geologic phenomena accompanying their deposition, I would increase the comparative length of the Mesozoic and Cenozoic periods so that the time ratios would be: Paleozoic, 12; Mesozoic, 5; Cenozoic, including Pleistocene, 2.

DURATION OF POST-ARCHEAN GEOLOGIC TIME.

Taking as a basis 17,500,000 years for Paleozoic time, and the time ratios 12, 5, and 2 for Paleozoic, Mesozoic, and Cenozoic (including Pleistocene), respectively, the Mesozoic is given a time duration of 7,240,000 years; the Cenozoic, of 2,900,000 years, and the entire series of fossiliferous sedimentary rocks, of 27,650,000 years. To this there is to be added the period in which all of the sediments were deposited between the basal crystalline Archean complex and the base of the Paleozoic. Notwithstanding the immense accumulation of mechanical sediments in this Algonkian time, with their unconformities, and the great differentiation of life at the beginning of Paleozoic time, I am not willing with our present information to assign a greater time period than that of the Paleozoic—or 17,500,000 years. Even this seems excessive. Adding to it the time period of the fossiliferous sedimentary rocks, the result is 45,150,000 years for post-Archean time. Of the duration of

* *Nature*, July 4, 1878, vol. XVIII, p. 268.

Archean or pre-Algonkian time I have no estimate based on a study of Archean strata to offer. If we assume Houghton's estimate of 33 per cent for the Azoic period and 67 per cent for the sedimentary rocks, Archean time would be represented by the period of 22,250,000 years. In estimating for the Archean, Houghton included a large series of strata that are now placed in the Algonkian of the Proterozoic of the U. S. Geological Survey; and I think that his estimate is more than one-half too large; if so, 10,000,000 years would be a fair estimate, or rather conjecture, for Archean time.

Period.	Time duration.
	Years.
Cenozoic, including Pleistocene	2,900,000
Mesozoic	7,240,000
Paleozoic	17,500,000
Algonkian	17,500,000
Archean	(?) 10,000,000

It is easy to vary these results by assuming different values for area and rate of denudation, the rate of deposition of carbonate of lime, etc.; but there remains after each attempt I have made that was based on any reliable facts of thickness, extent, and character of strata, a result that does not pass below 25,000,000 to 30,000,000 years as a minimum and 60,000,000 to 70,000,000 years as a maximum for post-Archean geologic time.

I have not referred to the rate of development of life, as that is virtually controlled by conditions of environment.

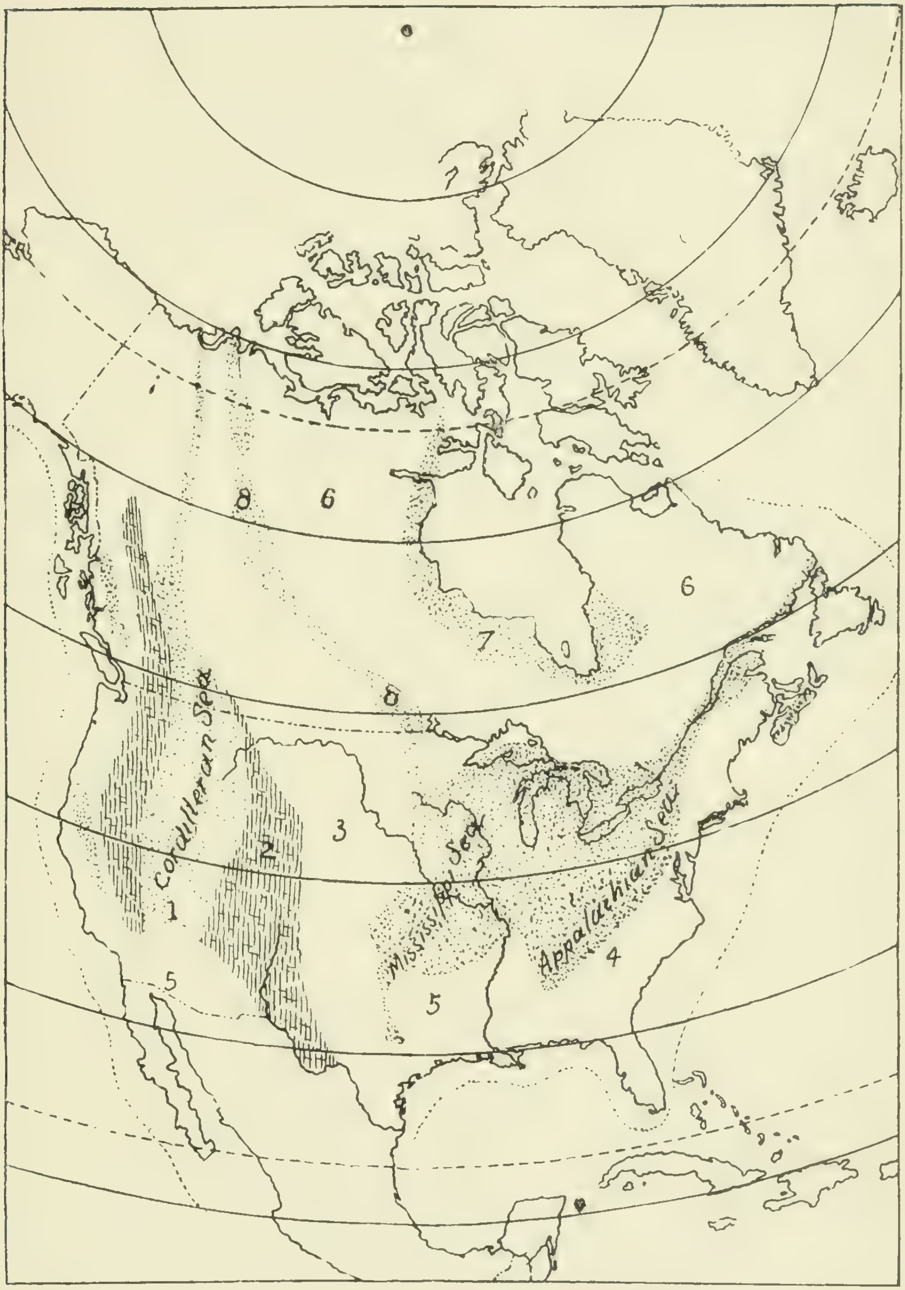
In conclusion, geologic time is of great but not of indefinite duration. I believe that it can be measured by tens of millions, but not by single millions or hundreds of millions, of years.

DESCRIPTION OF MAP.

On the map (Plate XVI) the hypothetical areas of the Cordilleran, Mississippian, and Appalachian seas are clearly indicated. The land area west of the Cordilleran sea is numbered No. 1, and the Californian sea and the area of Paleozoic deposits of western British Columbia, No. 10. The northern extension of the Cordilleran sea (No. 9) is continued as the Paleozoic-Devonian sea to the Arctic Ocean. The early Cambrian land area (No. 2) east of the Cordilleran sea must have been more or less covered by water during later Paleozoic time. The area now covered by Mesozoic deposits, indicated by No. 3, was presumably covered by the westward and northward extension of the Paleozoic-Mississippian sea. The area east of the Appalachian sea is indicated by No. 4; and the supposed land barrier between the Hudson Bay and the Mississippian sea by No. 6; it is not improbable that during Ordovician or Silurian time a sea may have connected the two latter seas.

The region to the south, indicated by No. 5, is supposed to have been covered by the southward extension of the Appalachian, Mississippian, and Cordilleran seas. It is now covered by deposits of Mesozoic and Cenozoic age.

A more detailed description of the map can be gained from the section on the growth of the continent and on the geographic conditions accompanying the different depositions of Paleozoic sediments in the Cordilleran sea.



HYPOTHETICAL AREAS OF THE CORDILLERAN, MISSISSIPPIAN, AND APPALACHIAN SEAS.

THE AGE OF THE EARTH.*

By Clarence King.

Among the various attempts to estimate geological time none has offered a more attractive field for further development than Lord Kelvin's mode of limiting the earth's age from considerations of its probable rate of refrigeration, published in 1862.† At that time the consequences of his physical reasoning could not be fully applied to the conditions within the earth, so as to test the probability of his hypothetical case, for want of positive knowledge of certain properties of rocks, particularly the volume changes of melted rock in approaching and experiencing congelation, and the qualitative and quantitative effects of pressure upon the fusion and freezing points. Data then lacking are for the first time available, and with them it is proposed to apply a new criterion to the gradient of Lord Kelvin and to compare with it other cases of more probable earth-temperature distribution, which should have the effect of advancing his method of determining the earth's age to a further order of importance.

Accepting the hitherto unshaken results of Kelvin and G. A. Darwin as to the tidal effective rigidity of the earth, and the further argument for rigidity advanced by Prof. S. Newcomb‡ from the data of the lately ascertained periodic variation of terrestrial latitude, as together warranting a firm belief in the rigid earth, it follows that solidity may be used as a criterion to test the probable truth of many cases of earth temperature distribution; at least so far as to justify the rejection of such as involve considerable liquidity of the upper couches. In an earth of which the superficial quarter of radius is composed of materials that contract from the fluid condition toward and in the act of congelation, any temperature gradient in which the downward heat augmentation exceeds the rate by which advancing pressure raises the fusion point, would obviously reach a fused couche, and all such distributions may be rejected as violating the requirements of rigidity.

* From *American Journal of Science*, January, 1893, 3d series, vol. XLV, pp. 1–20.

† *Treatise on Natural Philosophy*, Thomson & Tait, Part 2, Appendix D.

‡ *Monthly Notices of the Royal Astronomical Society*, 1892, vol. LII, No. 5.

A recent investigation of the rock diabase in its relations to heat and pressure offers the formerly lacking means of testing the admissibility of many cases of earth temperature distribution from the point of view of solidity. Ten years ago in a laboratory established by me in connection with the U. S. Geological Survey, Dr. Carl Barus began a series of experimental researches tending toward the solution of some of the unknown but important points of geological physics. It has been my privilege to indicate the direction of much of the inquiry. The understanding between us maintained his entire independence in the mode and prosecution of the investigations, and secured for him the fullest responsibility and credit for the purely physical results, many of which have at intervals appeared in this and other journals. For myself was reserved the privilege of making geological applications of the laboratory results. One of the most important of these is Dr. Barus's lately completed determination of the latent heat of fusion, specific heats melted and solid, and volume expansion between the solid and melted state, of the rock diabase.* To him I am also very generally indebted for aid in considering the present problem.

Diabase was chosen by me as fairly illustrative of the probable density and composition of the surface 0·03 or 0·04 of the earth's radius. For Laplace's law of distribution, density at the surface is taken at 2·75 and down one-tenth of radius at 3·88, yielding a mean density of the whole tenth of 3·33 and for the upper five-hundredths of about 3. For the whole tenth a rock like the extremely heavy basalt of Barenstein† (sp. gr. 3·35) would approach closely a fair mean expression of density. Typical hornblende-andesite comes closest to the average density at the surface, but diabase (sp. gr. 2·8 to 3), nearly enough fills the conditions of the shell which this study seeks to investigate. The particular diabase under examination came from Jersey City, and was taken from the immediate vicinity of the Pennsylvania Railroad cut.

The following analysis is by G. W. Hawes:‡

Silica	53·13
Alumina	13·74
Ferrous oxide	9·10
Ferric oxide	1·08
Manganous oxide	0·43
Lime	9·47
Magnesia	8·58
Soda	2·30
Potash	1·03
Ignition	0·90
	99.76

Astronomical and geodetic requirements make necessary that density should proceed downward in shells of successively greater value, but the surface density is 2·75 and the mean density of the whole earth is

* *Am. Jour. Sci.*, December, 1891, and January, 1892.

† J. Roth, *Gesteins-Analysen*, 1861, p. 46.

‡ *Am. Jour. Sci.* (III), vol. IX.

not twice that of diabase, whence it appears that no probable chemical distribution of material could result in a surface couche of 0·05 of radius having a greater specific gravity than 3· to 3·3.

Waltershausen,† in his interesting scheme of chemical distribution, attempts to account for the augmentation of density chiefly by the increase of the heavy bases, but leaves the whole surface tenth of radius in silicates. Eruptions of alkaline earths or metals are unknown. In fact, with the exception of carbonates of superficial origin the whole visible body of the crust is of silicates, and the earliest rocks are seen to be made of the débris of still older ones. All that can be said is that there is absolutely no known reason why the surface tenth of radius may not be of silicates, nor why specific material of widely different thermal properties from diabase should be postulated.

The two principal conditions within the interior of the earth, upon which physical state and all purely physical reactions of the specific materials depend, are the distributions from center to surface of pressure and heat. Secular or sudden variations of either or both have the power, if carried sufficiently far, to disturb chemical and physical equilibrium and produce changes of volume, rigidity, viscosity, and conductivity, as well as changes of state from liquidity to solidity, and the reverse. Before proceeding to consider in detail some of the results of heat and pressure as existing in the surface 0·05 of radius, it is desirable to glance at the relations of these two great antagonistic energies in the whole radius. Plate XVII gives earth-pressures from Laplace's law expressed in a gradient of which the ordinates are 100,000 atmospheres (larger divisions 1,000,000 atmospheres) and the abscissæ tenths of radius. Upon the same diagram are delineated two hypothetical cases of earth temperature, the abscissæ remaining as for the pressure line, tenths of radius, and the ordinates corresponding in interval to the 100,000 atmospheres lines, are taken as each 1,000° C. The left vertical boundary of the plate represents the center of the earth and the right one the surface. The upper heat gradient corresponding to a temperature of 3,900° C. at the earth's center is the 100×10^6 curve of Kelvin. The lower is computed for a central temperature of 1,741° C., about the melting point of platinum, and a secular cooling in 20×10^6 years. Data for the construction of these gradients are given in the tables a few paragraphs later. The feature here called attention to is the exceedingly slight change of temperature from very near the surface downward to the center. In the Kelvin gradient even after the lapse of 100×10^6 years the original maximum temperature is reached within 0·05 of radius and remains thence unchanged to the center. Pressure, on the other hand, augments with one downward sweep through the entire radius. On plate XVII its line is seen cutting both temperature gradients near the surface, passing the 1,741° C. line at a pressure of 175 000 atmospheres, and the Kelvin line at 390,000 atmos-

* "Rocks of Sicily and Iceland."

pheres; thence steadily augmenting until at the center it reaches the impressive figure of 3,018,000 atmospheres.

Since we are to look to heat and pressure for the keys to the physical condition of the matter of the earth, it is important to realize from the relation of these gradients, first, that the great effect of heat in opposing and overcoming the results of pressure must be limited to superficial earth-depths not exceeding 200 miles for an earth of the Kelvin assumptions; secondly, that below this depth and onward to the center there is a complete reversal of relations and a great and continual increase of pressure available to oppose and destroy the volumetric and other molecular effects of a temperature which has ceased to increase. The empire of heat over pressure is thus seen to be purely superficial, while that of pressure over heat begins not far below the surface and extends more and more powerfully to the center. This is obviously true only for such moderate assumptions of heat and time as are given in the gradients on Plate XVII, but it will be shown later that these figures are, upon the criterion of solidity, far more probable than very hot or very old earths.

Out of the infinite number of possible earth-temperature gradients to discriminate the probably true case, is of critical importance in any attempt to determine the earth's thermal age or to delimit the period of active geological dynamics.

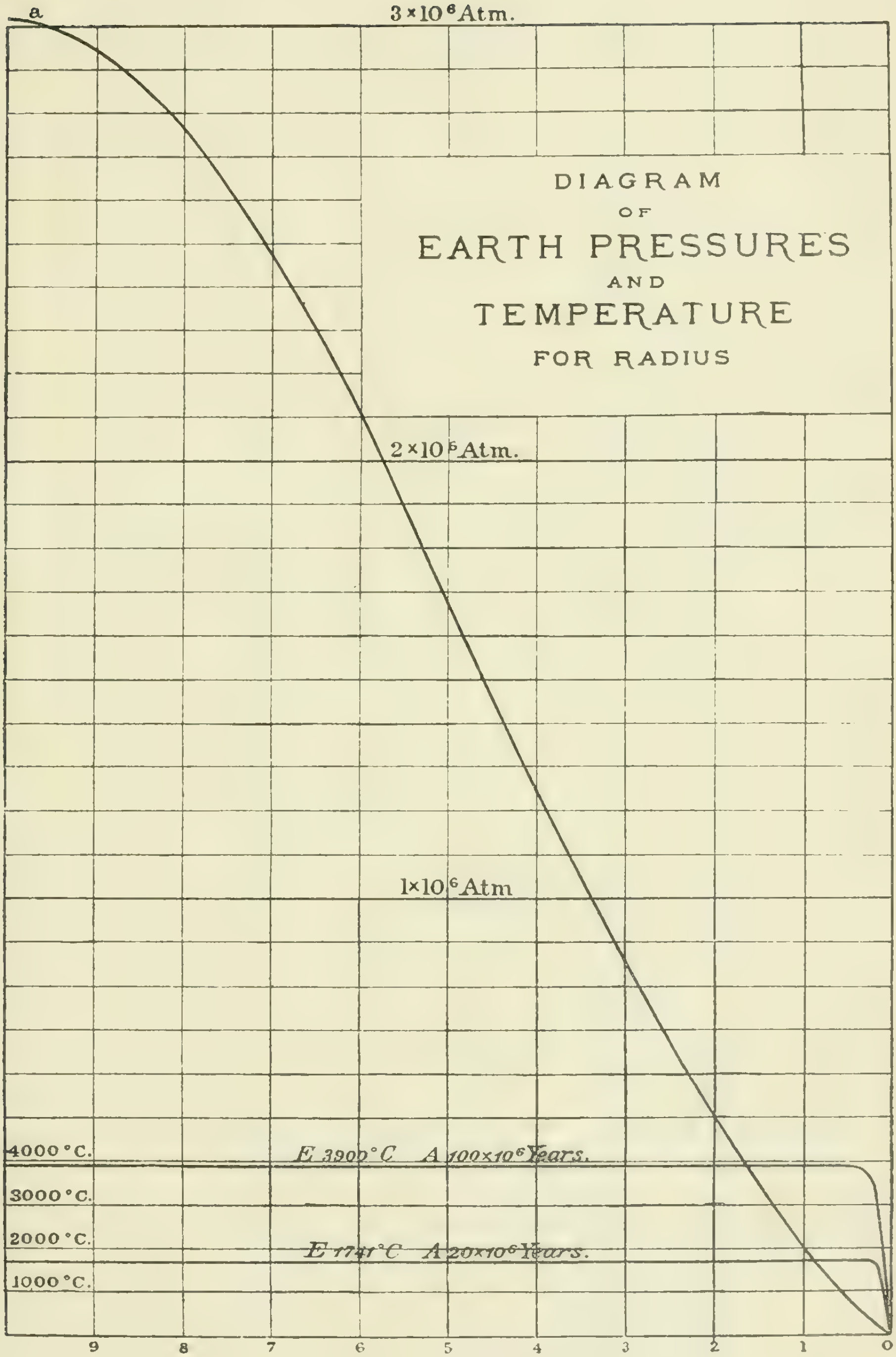
PRESSURE AND TEMPERATURE TABLES.

The following tables offer figures for the construction of the pressure and some of the temperature gradients on both Plates XVII and XVIII. Data for the distribution of earth-pressure may be obtained either from the formula of Laplace or that of G. H. Darwin for radial earth density, combined with the known decrease of terrestrial gravitation from center to surface.

In table 1, Laplace's law is used as giving the most conservative values of density at great depths. For the superficial 0·2 of radius, however, the two density laws are near together, and as the thermal phenomena which determine the earth's age are probably wholly in the surface tenth, either law might be applicable to the present purpose. As, however, Darwin's law requires a surface density of 3·7, while Laplace only 2·75, the latter accords better with the average specific gravity of superficial rocks and is therefore here preferred.

Tables 2, 3, and 4 give data for three temperature gradients derived by mechanical quadrature from the well known Fourier equation in the manner given by Lord Kelvin, and are considered as sufficient in number and variety to indicate the character of the data; figures for the other gradients shown on Plate II are therefore omitted.

Table 2 presents data for the Kelvin gradient, 3 900° C. initial excess, surface rate 0.03600 in degrees centigrade per meter of depth, and secular cooling 100×10^6 years. Earth temperatures in ° C. are given for depths that are expressed both in miles and fractions of radius and



a
3×10⁶ Atm.
DIAGRAM
OF
EARTH PRESSURES
AND
TEMPERATURE
FOR RADIUS
2×10⁶ Atm.
1×10⁶ Atm
4000 °C.
3000 °C.
2000 °C.
1000 °C.
E 3900 °C A 100×10⁶ Years.
E 1741 °C A 20×10⁶ Years.
9
8
7
6
5
4
3
2
1
0

extend to 250 miles or about 0·06 of radius. Surface rate appears both in ° F. and feet, and ° C. and meters. Tables 3 and 4 exhibit similar data for earths of lower initial excess and shorter periods of secular cooling. Table 3 is computed for an earth of 1,740° C., 20×10^6 secular cooling, and table 4 for 1,230° C., 10×10^6 cooling.

TABLE No. 1.—*Estimated earth pressures (Laplace's densities), n being radial distances from the center of the earth and p being the pressure corresponding to n expressed in atmospheres.*

n. Earth radius.	p. Atmosphere.	n. Earth radius.	p. Atmosphere.	n. Earth radius.	p. Atmosphere.
1·000	0	0·94	116,000	0·5	1,680,000
0·995	8,600	0·92	162,000	0·4	2,100,000
0·990	17,400	0·90	199,000	0·3	2,470,000
0·985	26,400	0·80	497,000	0·2	2,770,000
0·980	35,600	0·70	852,000	0·1	2,950,000
0·960	74,500	0·60	1,260,000	0	3,020,000

TABLE No. 2.—*Estimated earth temperatures. Initial excess of 3,900° C. 100,000,000 years' secular cooling with surface rate of 1° F. for 50·6 feet of depth. Thermal conduction 400 feet² /year (Lord Kelvin's case.*

Miles deep.	Rate in ° F. and feet.	Rate in ° C. and meters.	Temperature in ° C.	Depth in earth radius.
0	0·01977	0·03600	0	0·00000
12	0·01924	0·03510	726	0·00312
25	0·01773	0·03230	1,412	0·00625
50	0·01279	0·02330	2,543	0·01250
75	0·00742	0·01350	3,275	0·01875
100	0·00346	0·00630	3,658	0·02500
125	0·00129	0·00236	3,825	0·03125
150	0·00039	0·00071	3,881	0·03750
175	0·00009	0·00017	3,897	0·04375
200	0·00002	0·00003	3,901	0·05000
225	0·00000	0·00001	3,902	0·05625
250	0·00000	0·00000	3,902	0·06250

TABLE No. 3.—*Estimated earth temperatures Initial excess 1,741° C. (about melting point of platinum) 20,000,000 years' secular cooling with surface rate of 1° F. to 50·6 feet of depth. Thermal conduction 400 feet² /year.*

Miles deep.	Rate ° F. and feet.	Temperature ° C.	Depth in earth radius.
0	0·01797	0	0·00000
6	....	359	0·00156
12	0·01726	693	0·00312
25	0·01147	1,218	0·00625
37	0·00581	1,534	0·00937
50	0·00224	1,675	0·01250
62	0·00066	1,725	0·01562
75	0·00015	1,738	0·01875
87	0·00002	1,741	0·02187
100	0·00000	1,741	0·02500

TABLE No. 4.—*Estimated earth temperatures. Initial excess 1,230° C. 10,000,000 years' secular cooling with surface rate of 1° F. to 50·6 feet of depth. Thermal conduction 400 feet² /year.*

Miles deep.	Rate ° F. and feet.	Temperature ° C.	Depth in earth radius.
0	0·01977	0	0·00000
12	0·01506	662	0·00312
25	0·00665	1,063	0·00625
37	0·00171	1,198	0·00937
50	0·00025	1,227	0·01250
62	0·00002	1,230	0·01562
75	0	1,231	0·01875
87	0	1,231	0·02187
100	0	1,231	0·02500

TABLE No. 5.—*Estimated melting point and depth for the rock diabase expressed in radial earth distance, pressure and melting temperature.*

n. Earth radius.	p. Atmosphere.	θ_m. °C.	n. Earth radius.	p. Atmosphere.	θ_m. °C.
1·000	0	1,170	0·920	162,000	5,210
0·995	8,600	1,380	0·900	199,000	6,100
0·990	17,400	1,600	0·8	497,000	14,000
0·985	26,400	1,830	0·6	1,260,000	33,000
0·980	35,600	2,060	0·4	2,100,000	54,000
0·960	74,500	3,030	0 2	2,770,000	71,000
0·940	116,400	4,080	0·0	3,020 000	76,000

Table 5 contains a prolongation of Barus's line of melting point and depth for the rock diabase, expressed in radial earth distance n, pressure p (Laplace's densities), and melting temperatures, θ_m.

THE CHART.

The chart constituting Plate XVIII is constructed to present the passage of certain hypothetical temperature gradients through the uppermost 0.08 of the earth's radius, and the position in the same field of Barus's line marking the melting point in depth of diabase, thus defining the relations of the various distributions of earth-temperature to liquidity. The value of the ordinates is each 1,000° C. the abscissæ, which are platted as equal in length to the ordinates, represent hundredths of radius counting downward from the surface which is indicated by the right vertical boundary of the chart.

Kelvin's application of the Fourier equation involves an assumed initial excess of temperature, and assigned value of rock conductivity, a given period of secular cooling, and the surface rate of augmentation of earth-temperature. As thus applied to the case of the cooling earth, it is obvious that while the body was of uniform initial heat there would be no augmentation of temperature from the surface downward; or other-

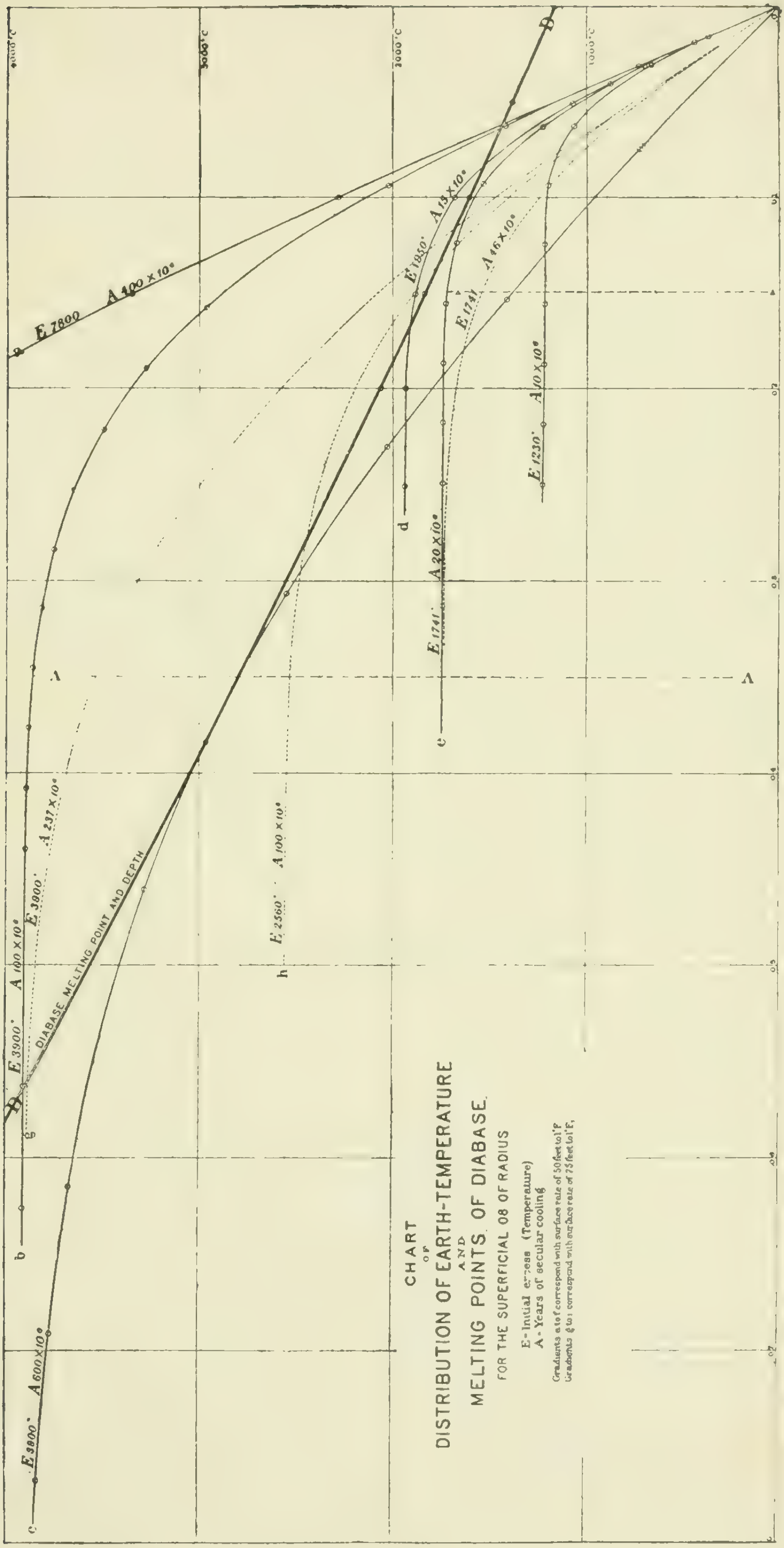


CHART
OF
DISTRIBUTION OF EARTH-TEMPERATURE
AND
MELTING POINTS OF DIABASE
FOR THE SUPERFICIAL 08 OF RADIUS
E - Initial excess (Temperature)
A - Years of secular cooling
DIABASE MELTING POINT AND DEPTH
E 7800
A 100 X 10⁶
E 3900°
A 100 X 10⁶
E 3800°
A 600 X 10⁶
E 2560°
A 100 X 10⁶
E 1741°
A 20 X 10⁶
E 1230°
A 10 X 10⁶
A 46 X 10⁶
A 15 X 10⁶
E 1850°
1000°C
2000°C
3000°C

wise expressed, the surface rate would be ∞; but the moment refrigeration began a finite rate of downward increment would be established. Since the earth's surface is represented on the chart by the right vertical boundary, that line would be the thermal distribution for the rate ∞. A complete process of refrigeration would cause the rate to decline until the earth reaches the temperature of space and the line of initial tangency coincides with radius, and the rate 0. The angular relation of the initial tangent of the present as compared with that of the rate ∞ is determined from observed surface augmentation.

The value of the integral and the surface rate for any gradient does not change if conductivity and age vary reciprocally, and the surface rate does not change if the initial excess of temperature varies at the same rate as the square root of the product of conductivity and the time of secular cooling. If the square root of the product of conductivity and age be increased any number of times, and the depth also be increased the same number of times, temperature remains unchanged if the initial excess is unchanged, but if the initial excess changes, temperature will change in the same ratio.

Upon the chart are delineated two families of temperature distributions. Those in continuous lines, lettered *a* to *f*, are calculated in accordance with the maximum surface rate of 50.6 feet to 1° F., being the generally accepted rate at the time Kelvin's curve was published. Those in dotted line, and lettered *g* to *i*, are constructed for the rate of 75 feet to 1° F., the smallest of the observed inland rates. It is the value given by Hallock * for the recently completed boring near Wheeling, W. Va. The last published value as reduced from all available data by the B. A. committee is 64 feet to 1° F. It is therefore extremely probable that unless some general but unrecognized cause, like a variation of temperature due to the chemical action of hot water and progressive downward either with heat or pressure, tends to raise or lower the mean rate, the true surface distribution falls between the values of 50.6 and 75 feet per ° F. upon which the two families of gradients are based.

The diabase line for melting temperature and depth D D is traced from its superficial fusion point, 1,170° C. downward, according to the law established by Dr. Barus and expressed in table 5. This is the special point of interest in the chart and in the conclusions to which it gives rise. In passing from this surface value of 1,170° C. through 0.1 of the radius, the fusion temperature is raised to 6,139° C.; continuing thence to the center of the earth it reaches the surprising value of 76,200° C. In consequence in an earth all of diabase any temperature gradient having an initial excess of less than the above central value must in reaching the surface either intersect the line D D twice or fall wholly beneath it. Since this line represents melting temperature, any point vertically above it in the chart is necessarily more highly heated than

* *Am. Jour. Sci.*, vol. XLIII, p. 234, 1892.

the melting temperature for the same depth, and hence in fusion. Conversely, any point below the diabase line, being below the melting temperature for that pressure and depth, falls into solidity. Thus the chart is divided into two areas by the line, that above it representing fluidity, and that below, solidity. For a diabase earth to have been wholly melted an initial excess of 76,200° C. would be required. Obviously any earth having an initial excess of less than the surface melting point 1,170° C. would have been always completely solid. Any initial excess above that figure and below 76,200° C. requires, at the moment before refrigeration began, a solid nucleus and a fused zone above it extending to the surface, and the lower the initial excess the larger the solid nucleus of compression and shallower the initial couche of surface fusion. Knowing the law of the rise of the fusion-point it is a simple matter of computation to determine, for any assumed initial excess, exactly the radial value of the original solid nucleus and of the original supernatant fluid couche. For the region covered by the chart these values may be directly scaled off.

Fourier's equation enables us to go further and assuming that refrigeration is the result of conduction alone, to determine the temperature distribution for any given period of refrigeration, and what is of particular geological interest—the rate at which the fused couche is encroached upon by an overlying superficial crust of congelation, and the existence, depth, temperature, and pressure differences of any residual fluid couche between the upper and lower solids. The relation therefore of any temperature gradient to the diabase line offers an immediate test of its admissibility as a probable case. Any temperature gradient that in passing across the area of the chart from below to the surface intersects the diabase line must in reaching the low temperatures of the surface intersect it again, and the zone included between the pair of points of intersection being above the line, and hence for that interval of radius above the fusion temperatures, must be a melted shell, and as on the criterion of solidity the existence of any considerable fusion is precluded, such a case of temperature distribution may be rejected.

I will now trace the several temperature distributions upon the chart, and note their relations to time and solidity, beginning with the family delineated in continuous lines (surface rate 50.6 feet to 1° F.). Line *b*, the gradient of Kelvin, 3,900° C. initial excess, 100×10^6 years secular cooling, is seen to enter the chart from the lower regions, maintaining even to the shallow depth of 226 miles from the surface, practically, its original maximum temperature. From the center of the earth up to this point it has remained in the initial solid of compression. At the depth noted it intersects the diabase line and passes into fusion. Since almost the full initial temperature is maintained up to its intersection, it follows that that depth nearly marks the original surface of the solid nucleus and that the distance of 226 miles thence to the sur-

face measures the depth of the original couche of fusion. Following the gradient toward the surface, it is seen (after describing its great convexity in the fluid region) to intersect the diabase line a second time and enter a congealed shell or crust formed by cooling a surface portion of the initial fused couche, and leaving between the nucleus and crust a residual present shell of fusion of 200 miles from the top to the bottom. The obvious tidal instability of a 26-mile crust resting upon 200 miles of truly fluid magma is sufficient basis for the rejection of this particular case of temperature distribution. To fulfill the requirements of rigidity either the time of cooling must be vastly greater to admit of entire congelation, or the initial excess materially less.

As an illustration of the first of these alternatives, gradient *c* with the same initial excess as *b* (3,900° C.) has been developed to complete solidity, which on computation proves to have required about 600×10^6 years, at which time it has but just reached tangency with the diabase line. Yet we are absolutely precluded from accepting it as a probable case and assigning 600×10^6 years as the age of the earth, because the temperature values of its emergence at the surface fall below even the 75 feet to 1° F. surface rate. Its emergence is at a rate of 0·0081° F. per foot (124 feet per ° F.), which is far less than the (Hallock) rate used in the dotted gradients, itself much less than the accepted mean rate of the British Association committee.

Gradient *d*, 1,950° C. initial excess, and 15×10^6 years secular cooling, falls still some millions of years short of solidity. The initially fused surface couche was about 66 miles in depth, the present crust 33 miles thick, and the present residual fluidity of 33 miles depth from top to bottom. Here again the liquid zone involves tidal instability and requires the rejection of the line.

Gradient *e* offers more satisfactory conditions: With an initial excess of 1,750° C., about the normal melting point of platinum, and an age of 20×10^6 years, a condition is reached which throws the convexity of the gradient below the diabase line in complete solidity and fulfills all the conditions. Here then is a possible age for an earth of diabase. Its initial surface couche of fusion would have been about 53 miles, and is now wholly cooled into solid crust and united with the original solid nucleus of compression.

Gradient *f*, initial excess 1,230° C. and 10×10^6 years secular cooling, would in its first stage have shown only about 5 or 6 miles of surface fusion, which would very shortly have cooled into solidity.

For those whose interest centers in earths of great age and high temperature, gradient *a* is given, initial excess 7,800° C and 400×10^6 years secular cooling. This has not been projected to the deep, but would not reach solidity until over $1,500 \times 10^6$ years, a truly uniformitarian specimen.

Turning now to the family of three gradients in dotted line, computed to conform to the surface rate of 75 feet to 1° F., the first, *g*, is

seen to be of the same initial excess as the Kelvin 3,900° C. line. In spite of its long cooling even after 237×10^6 years it is still very far from solidity. Of the original fluid couche of 226 miles, only about 60 miles has been congealed into crust, 166 miles remaining fused.

Gradient *h*, initial excess 2,560° C., and a 100×10^6 years refrigeration has an original fluid couche of 120 miles with a present crust of 56 miles and an existing residual couche of fusion of 64 miles, a case also inadmissible from the point of view of instability.

Gradient *i*, initial excess 1,760° C. (platinum melting point), and 46×10^6 years of cooling, had originally a 53-mile surface couche of fusion which has long since passed into solidity. The following table sums up the condition of all the gradients as to initial excess, initial depth of surface fusion, time of cooling, thickness of crust congealed, and present residual couche of fusion:

TABLE 6.—*Liquid solid conditions for diabase earth.*

A.—*Gradients having the surface rate of 50·6 to 1° F.*

Initial excess.	Initial depth of surface fusion.	Time of cooling.	Thickness of crust congealed.	Residual couche of fusion.
°*C.*	*Miles.*	*Years.*	*Miles.*	*Miles.*
3,900	226	100×10^6	26	200
1,950	66	15×10^6	32	33
1,741	53	20×10^6	crust and nucleus united	0
1,230	6	10×10^6	crust and nucleus united	0

B.—*Gradients having the surface rate of 75 feet to 1° F.*

3,900	226	237×10^6	50	166
2,560	120	100×10^6	56	64
1,741	53	46×10^6	crust and nucleus united	0

Comparison of gradients of equal initial excess and successively longer periods of secular cooling shows the ratio of their retreat from right to left across the chart or from lower to higher values of depth and time.

With each augmentation of age the initial tangent defining the surface rate is seen to have declined further and further from the original rate ∞, coinciding with and passing first the maximum, then the minimum rate thence declining into the region of inadmissible rates.

The probable conditions of the true gradient are as to initial excess and age such as fall below the diabase line into solidity and emerge at the surface with a rate which has not declined below the mean (B A) rate of 64 feet to 1° F. From the point of view of solidity no gradient of initial excess above 2,000° C. is admissible; that of 2,560° C., even after 100×10^6 years cooling, still shows a deep shell of fusion (64 miles

from top to bottom), and since it emerges on the minimum rate it has already fallen below the admissible tangent.

Gradient *d*, 1,950° C. and 15×10^6 years, just cooled to the maximum surface rate, has still an inadmissible fluid shell, but if refrigeration had been continued for 7×10^6 to 9×10^6 years more the line would have fallen below the solidity line and its surface rate would not have passed the mean value. Hence a 1,950° 24×10^6 year earth is possible and marks about the superior limit admissible for initial excess.

From the point of view of age no greater time of cooling is allowable than enough to bring the gradient for any initial excess to the mean surface rate. Thus the condition for excess and age exclude a line of over 2,000° C. and 24×10^6 years. Conductivity remaining of the value used, any higher excess involves fluidity, and any greater age an inadmissible surface rate.

To the extent, therefore, that solidity is a valid criterion and so far as the melting temperature of diabase may be supposed to apply to the depth examined, there is no escape from an earth of the low age and temperature given except by impugning the rate of surface augmentation and the value of rock conductivity here employed.

Whoever has examined the B. A. committee's reports and summaries on underground temperatures must have realized the obstacles to the evaluation of a true mean rate. The range of observations is wide, from high rates due to residual vulcanism to low ones produced by neighboring bodies of cold water, such as are described by Wheeler from mines near Lake Superior.* It is not however likely that by rejecting anomalies and assigning probable weight to further observations the present value will be moved to an important extent.

We have seen that all probable distributions of earth temperature involve in the initial stage a great solid nucleus, practically the whole body of the earth, with a shallow surface shell of fusion. In the case of the 1,741° C., 20×10^6 year earth there was an initial melted shell of 53 miles. Obviously it can not be correct to apply the rock-conductivity value obtained at air temperatures and normal pressure to even so young and cool an earth with its couche of an initial temperature of 1,741° C. and a pressure difference between the top and bottom of 22,000 atmospheres. The probable method of cooling the couche into solidity, involves three corrections of the accepted rate of refrigeration: *a*, acceleration of the process by possible convection; *b*, the direct effect of heat and pressure upon conductivity, and *c*, the relative conductivity of matter at the some temperature, liquid and solid.

a. Convection. Leaving out of present consideration possible polymerization of the magma, or the descent of solid bodies of crust, vertical transfers of the liquid matter in the fused couche depend upon differences of density and this upon the ratio of the rates at which density is raised by pressure and lowered by heat. Isometrics of melted

* *Am. Jour. Sci.*, 1886, vol. XXXII.

rock under high pressure are of course beyond the reach of experimentation, hence we are forced to look to those of the available materials. Isometrics from high-pressure observations have been found to slope as follows:

	Atmosphere per $^\circ$ C.
Ether	8·7
Alcohol	10·5
Thymol	13·9
Dyphenylamine	15·4
Paratoluidine	13·9
Glass, computed	10·0

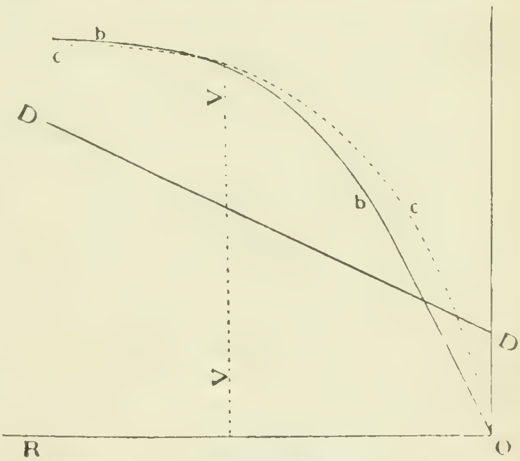
Since ether boils at 34° C. and dyphenylamine at 310° C., the range here given is wide. It is reasonable, therefore, to take the mean value, 12·5 atmospheres per C., as an index of the slope sought for. In the Kelvin earth this rate occurs between 0·010 and 0·015 of radius, the crust being 0·0065 of radius thick. In so far therefore as the isometries can be regarded as parallel straight lines with a slope of the order of the value given above, convection can only have taken place in the first 52 miles of the initial couche of fusion, and in the present residual couche of 200 miles only the upper 26 miles would be subject to convection. In younger earths the above value per $^\circ$ C. will be found much nearer the surface, so that in them convection would be confined to a shell, which is shallow in proportion as the earth is young. Initially when the whole earth was at one temperature there could have been no convection, since the change of temperature in depth was *nil*, but the change of density due to pressure was always pronounced. In the case of the 1,741° C. earth the zone of convection would have early been covered and extinguished by the thickening crust, and therefore would have played no very important part in accelerating the loss of heat, and thus for this particular initial excess is of small effect in shortening the estimate of earth's age.

b. The direct effects of heat and pressure upon the conductivity of matter under such high temperature and pressures are also beyond laboratory investigation, and again we are driven to use the determined conductivity value unmodified, or seek for some other property which may be considersd as its approximate measure. Such an index is found in viscosity, which if not of high quantitative significance in defining the changing values of terrestrial conductivity in depth, nevertheless affords data applicable at least for determining the sign of an important correction.

Dr. Barus has lately determined that at least 200 atmospheres of pressure are required per 1° C. in order that viscosity may remain constant. Examining several temperature distributions of the chart and applying the computed augmentation of earth pressure, it appears that the required relation (200 atmospheres to 1° C.) is found at successively lower depths for successively higher values of initial excess and age. In the 1,741° C. case the relation after 20×10^6 years' cooling is found at about 016 of radius counting from the surface, where the vertical

broken line *r r* of the chart intersects the gradient and marks the locus of stationary viscosity. As above this point temperature relatively to pressure has augmented more rapidly than the ratio required for constant viscosity, it follows that viscosity has been diminished by temperature more than it has been raised by pressure. Below the stationary point, on the other hand, an excess of pressure above the required ratio is available for increase of viscosity.

For the gradient of 3,900° C. excess the transitional depth is indicated by the intersection of the broken line *V V*. In both cases the transitional points occupy positions in their respective gradients not far below their full initial temperatures, and pressure having been most stationary the transitional points have moved but little during the whole period of secular cooling, and the earth shells passing through them have divided radius into a lower solid of higher viscosity and a surface couche, partly liquid, partly solid of lower viscosity. So far therefore as viscosity indicates the behavior of conductivity, that also should have been systematically diminished (relatively to the surface value obtained at normal pressure and temperatures and used in the construction of the gradients) from the surface downward for a small fraction of radius, till at the appropriate depth for each excess and age of cooling it reaches a transitional value and thence increases.



How this correction, of at present unknown value, affects the coordinates of a given gradient qualitatively, is shown by the following figure, in which are given the diabase melting point and pressure line, *D D*, gradient *b* of 3,900° C. excess and 100×10^6 years' cooling, with the viscosity transitional line *V V* intersecting it, also a dotted line *c*, indicating the position of the *b* gradient corrected for diminished conductivity (viscosity).

Lagging to the right of the uncorrected gradient, obviously the dotted line would require longer refrigeration to reach the state of solidity, and it is equally important to note that its position requires its emergence at the surface with a higher rate than the uncorrected line, and thus extends the time of cooling down to the mean rate which marks for all gradients the present limit of the process.

c. Liquid-solid conductivity. Closely involved in the above heat-pressure-viscosity correction is the change of conductivity on passing

isothermally from solid to liquid. Here again the results of Dr. Barus* throw important light.

The relatively higher thermometric conductivity of the solid over the liquid of equal temperature indicates an additional plus correction for time values.

Both the minus correction due to convection, and the plus corrections based upon conductivity diminished below the Everett figures, sink in importance as we pass from earths of higher to those of lower initial excess, so that until some approximate quantitative values can be given them we have no warrant for extending the earth's age beyond 24,000,000 years.

That the application of the criterion of solidity here made to Kelvin's method is open to the objection of being based on the physical relations of an extremely superficial fraction of radius is obviously true. Ignorance of the deeper interior distribution of specific materials and of their relations to the degree of heat and the range of pressure to which they are subjected forbids the construction of a generalized line of melting temperatures for the whole of radius.

It might therefore be contended that a reversal of the diabase conditions is possible, and the deeper materials may possess the property of ice fusion, their melting temperatures suffering depression instead of elevation. The high densities required in lower earth depths have constantly suggested the concentration there of heavy metals and the examples of meteorites has further influenced the idea of a metallic nucleus chiefly of iron. And as iron at normal pressure unmistakably exhibits ice fusion, any great iron mass at the center might be supposed to exist as a liquid in spite of the enormous pressure there exerted.

The distribution of materials and of "state" under this assumption involves a metallic (iron) nucleus, liquid from ice fusion, overlaid by less dense couches which at some unassignable depth pass into silicates of the diabase type, solid from compression under the law shown for diabase, and solid to the surface as required by tidal effective rigidity.

Ice fusion however is an exceptional phenomenon, nor have we any but the most limited data as to its range as regards temperature and pressure. Iron is conceded to contract in the act of fusion, but cold iron is more dense than the substance either just above or just below the fusion point. It is not beyond the range of probability that excessive pressures might bring about the same density in iron that cooling does, and thus isothermally convert ice fusion into the normal type and produce a solid nucleus. However that may be, tidal effective rigidity excludes fusion of either type for at least 0·2 of radius.

*The change of heat conductivity on passing isothermally from solid to liquid. C. Barus, *Am. Jour. Sci.*, July, 1892.

Other methods have been used for obtaining a measure of the earth's age, or for some definite portion of geological time.

EARTH AGE FROM TIDAL RETARDATION.

Kelvin's comparison of the earth's present figure with that of a thousand millions of years ago, when the terrestrial day would have been only half its present length, is one of the most interesting. The earth, if then plastic, would have yielded to four times the present centrifugal force at the equator and shown a correspondingly greater flattening at the poles and bulging at the equator, and "therefore," as Tait expresses it, "as its rate of rotation is undoubtedly becoming slower and slower it cannot have been many millions of years back when it became solid, else it would have solidified very much flatter than we find it." This implies that because a computed earlier and greater value of ellipticity does not now exist it could never have existed, in other words, that terrestrial rigidity has been and is of such value that a form taken in the remote past by the solid earth would not be modified by the tidal retardation of rotation and its attendant change of centrifugal force.

There is in modern geology a growing body of evidence which is believed to prove the very general plasticity of the lithosphere, by which it may experience important deformations from very *slowly* applied stresses. So strongly has this belief taken root that many American geologists accept "isostasy" and consider it to be an expression of a fluid equilibrium for the earth.

From abundant geological observation plasticity must be admitted for slow deformations enormously in excess of the small change of figure which the stress of tidal attraction would produce but for elastic resistance.

Although rigidity prevents a sudden tidal deformation of 5 feet, it does not prevent a slow radial deformation of 5 miles of the surface matter. How, then, can it be supposed to resist the slow change of stress due to tidal retardation of rotation? The excess of the equatorial over the polar axis is now roughly 25 miles, while the radial range of surface inequalities of the lithosphere is about 12 miles, of which a large part dates from this side of the beginning of Tertiary time. If past plasticity equals present values, the earth's figure could never have been a survival from some assumed earlier epoch when centrifugal force was greater, but must always have been a function of the slowly diminishing rate of rotation.

If the conclusions of the earlier portion of this paper are true they go further and exclude the idea of a formerly fluid earth and *any* epoch of solidification. With any admissible assumption of initial excess nearly the whole earth must have been solid from the date of the first collocation of its matter.

To whatever radial depth plasticity may descend, what is enough for

geologically recent superficial inequalities is sufficient for adjusting the figure of the earth to existing forces of rotation.

The same coast lines which remain stationary under tidal stress are slowly rising and falling in a hundred places under the slow application of subterranean energy.

It therefore appears that no time measure can be deduced from the supposed fixing of the present ellipticity at some past date.

ASTRONOMICAL MEASURE OF EARTH TIME.

Croll's hypothesis from which it was proposed to fix dates by secular variations of eccentricity and to correlate the *climatic* effects of those variations with geological operations, and thus measure certain intervals of geological time, required so much questionable physical geography and left so many physical doubts that few have been found to accept the excessively complex chain of effects lying between eccentricity data and geological facts. The objections of Prof. Newcomb, noticed rather than answered, left Croll's doctrine where it was permissible to believe that there was *something* in it, but not necessarily that definite sequence of climates which is the core of the idea.

The gap in Croll's scheme seems to have been successfully stopped by Sir Robert Ball, whose interesting proof of the seasonal inequality of the thermal element in climate due to position of the equinoxes and its intensification in periods of high eccentricity offers a new hope for the accurate dating of at least very modern geological climates. From this point of view late geological history requires re-examination, and if it should appear that a sequence of climates has existed closely parallelling the thermal variations which the astronomical values seem to afford, an extremely probable case will have been made out. And this case would be practically substantiated if the hypothesis of H. Blytt should yield the confirmation for which he hopes. Blytt * proposes and has already attempted to correlate the secular *attractional* changes due to varying eccentricity and precession with the observed successive shifting of beach lines.

So far as he has proceeded it is of interest to note that his time estimates are more in harmony with the physical than the stratigraphical figures.

Periodic changes in the figure of the hydrosphere relatively to the solid earth, due to alterations of attraction, might be predicted with some confidence if it were clear that the lithosphere would under the slow stresses involved continue to exercise a degree of rigid resistance comparable with that it opposes to the tidal stress, but there is no proof that it would.

Since we find the solid earth undergoing slow deformations to-day

* The probable cause of the displacement of beach lines. H. Blytt—1889, Christiania Videnskabs Fordhandlinger No. 1—Additional note 1889—second additional note 1889. (*Smithsonian Report* for 1889, p. 353.)

which are relatively permanent, while its effective elastic resistance to tidal stress is sufficient to permit a water tide, it appears that either the purely telluric stresses are greater than the moon's attraction, or that there is for the time rate of application of equal stress a transitional value above which the elastic resistance of the earth-solid is enough to conserve figure, and below which plastic deformation is easy—a relation of properties such as Kelvin suggests for the æther. Under the former alternative, deformations due to purely telluric forces might by upheaval or subsidence at any time mask or counteract astronomical beach shifting. In the latter case, to make use of the astronomical data for displacement of beaches, it is required to ascertain the time rate of terrestrial plasticity accurately enough to know that relatively to the duration of eccentricity and precession cycles and their correlative attractional variations, the reaction of the lithosphere would differ enough from that of the hydrosphere to allow of the beach shifting sought.

Beyond the most modern geological dates the grander earth deformations have carried ancient beach lines out of all recognizable radial relations with each other and the several oceans of which they mark the shores, or else, as is frequently the case with rising continents, they have been wholly effaced by erosion. Evidently the Croll-Blytt time measure, interesting as it may prove to be for recent dates, is at present inapplicable to any general determination of the earth's age.

EARTH-AGE MEASURED BY SUN-AGE.

Since the incrustment of the earth would be almost immediately followed by a climate controlled wholly by the sun's heat, re-distribution of the crust by water necessitates a sun heat received upon the earth's surface sufficient at least to maintain the temperature above that of permanent freezing.

Newcomb* remarks:

"If we reflect that a diminution of the solar heat by less than one-fourth its amount would probably mean an earth so cold that all the water on its surface would freeze, while an increase of much more than one-half would probably boil all the water away, it must be admitted that the balance of cause which would result in the sun radiating heat just fast enough to preserve the earth in its present state has probably not existed more than 10,000,000 years."

All we know of the earlier strata indicates a water mechanism for the denudation, comminution, and deposition of rock. Exactly the division of this work between tidal and river forces we may never know, but all evidences confirm the conviction that life was continuous from its earliest, or at least an early, appearance, and hence climate must have been continuously suitable for the circulation of continental waters. The range of temperature for the time since the beginning of the Huronian must have been well within Newcomb's limits. So that unless the

Popular Astronomy, p. 511.

selective absorption of either the sun's atmosphere or the earth's, or both, have varied reciprocally or concurrently with radiation, solar emission can not have had a wide range of either secular or paroxysmal change.

Nevertheless, the age assigned to the sun by Helmholtz and Kelvin (15×10^6 or 20×10^6 years) communicated a shock from which geologists have never recovered. The thermo-dynamic reasoning on which the brevity of the sun's life is reached stands undisturbed, yet so powerful is the influence of the old uniformation method of estimating the age of the total stratified crust, that to many geologists it has seemed easier to reject the physical conclusions than to seek a source of error in our own very vulnerable methods.

If, as I hold, Kelvin's suggestions as to ellipticity and tidal retardation do not apply to an earth readily deformable by slow stress, as this one evidently is, there remain but three earth-ages to be weighed—Kelvin's value from terrestrial refrigeration, which this paper seeks to advance to a new precision; Helmholtz and Kelvin's age of the sun, which must sharply limit the date of the re-distributed earth crust; and the old stratigraphical method. From this point of view the conclusions of the earlier part of this paper become of interest. The earth's age, about twenty-four millions of years, accords with the fifteen or twenty millions found for the sun.

In so far as future investigation shall prove a secular augumentation of the sun's emission from early to present time in conformity with Lane's law, his age may be lengthened, and further study of terrestrial conductivity will probably extend that of the earth.

Yet the concordance of results between the ages of sun and earth, certainly strengthens the physical case and throws the burden of proof upon those who hold to the vaguely vast age derived from sedimentary geology.

THE RENEWAL OF ANTARCTIC EXPLORATION.*

By JOHN MURRAY, LL. D.,

Of the "Challenger" Expedition.

When we cast a retrospective glance at the history of knowledge concerning our planet, we find that nearly all the great advances in geography took place among commercial—and in a very special manner among maritime—peoples. Whenever primitive races commenced to look upon the ocean, not as a terrible barrier separating lands, but rather as a means of communication between distant countries, they soon acquired increased wealth and power, and beheld the dawn of new ideas and great discoveries. Down even to our own day the power and progress of nations may, in a sense, be measured by the extent to which their seamen have been able to brave the many perils, and their learned men have been able to unravel the many riddles, of the great ocean. The history of civilization runs parallel with the history of navigation in all its wider aspects.

Horace and many other poets have sung the praises of the sailor who "first put forth on cruel ocean, in the frail rude bark." But in navigation, as in all other branches of human activity, there has been a slow, gradual, and laborious development from the construction and management of the simple raft by the river side up to the ironclad and Atlantic greyhound of our own day. Many active and original minds, many stout and brave hearts, have contributed to these final results. The tempest-tossed sea is now no obstacle and no terror for the instructed mariner with a well-found ship. The "severance of the sea" has disappeared along with the ideas associated with the expression. Not only so, but the most profound depths of the wide mysterious ocean have in our own time been forced to yield up their hidden treasures to the persistent efforts of the modern investigator.

Is the last great piece of maritime exploration on the surface of our earth to be undertaken by Britons, or is it to be left to those who may

* Paper read at the meeting of the Royal Geographical Society, November 27, 1893. (From *The Geographical Journal*, London, vol. III, pp. 1-27.)

be destined to succeed or supplant us on the ocean? That is a question which this generation must answer.

The civilized nations at the birth of navigation were most probably in the same phase of development as the Pacific Islanders of the present day. Yet it is a most remarkable fact that at the very dawn of history we find a commercial people who were able to conduct voyages which rival those of the fifteenth century. Long before the oldest Hebrew and Greek records, the Phenicians had settled all over the Mediterranean; they were in the Ægean fourteen—and at Gades on the Atlantic eleven—centuries before the Christian era; they made long voyages in the Erythræan Sea or Indian Ocean, as well as on the Atlantic beyond the Pillars of Hercules. Herodotus tells us that, about six hundred years before Christ, Phenician sailors reported that, in rounding Africa to the south, they had the sun on their right hand. "This, for my part," says Heordotus, "I do not believe; but others may." This observation as to the position of the sun is however good evidence that the expedition of Necho really took place. At all events this is the first hint to be found in literature of a visit to the Southern Hemisphere, and we do not meet with any more definite and satisfactory information till the time of the Renaissance.

For all practical purposes, the views of the later Greek philosophers, with reference to the figure and position of the earth, did not differ from those of the modern geographer, except in the difference between the geocentric and heliocentric standpoints. Eratosthenes estimated the circumference of the earth at 25,000 miles, a very remarkable approximation to the truth, and we find him speculating, eighteen centuries before Columbus and Magellan, on the possibility of circumnavigating the globe. The ancients divided the surface of the earth into five zones. The torrid zone was uninhabitable from heat; the two frigid zones toward the poles were uninhabitable from cold, and in the Southern Hemisphere there was a temperate zone similar to that of the Northern Hemisphere in which the known world was situated. Aristotle does not say that the southern temperate zone is inhabited, but Strabo admits that there may be other worlds inhabited by a different race of men. Pomponius Mela, who lived in the first century of our era, speaks as an undoubted fact of the existence of the autochthones inhabiting continental land in the Southern Hemisphere, although this land was inaccessible owing to the heat of the intervening torrid zone. Mela held (like most of his predecessors) that the habitable world of Europe, Asia, and Africa formed a single island surrounded by the all encircling sea. Marinus of Tyre, who lived in the second century, rejected this view, and returned to the less correct notion of Hipparchus, who had maintained that the known continents were united to other similar masses of land still unknown, and that the Atlantic and Indian Oceans were separated from each other, thus forming great inclosed seas, such as the Mediterranean. Ptolemy adopted the views

of Marinus, and consequently in his maps united the eastern coast of Africa by unknown lands or Southern Ethiopia to the Chinese coast.*

The science and learning of antiquity were swept away by the destructive incursions of the barbarians, and there is retrogression rather than progress to record during the dark and middle ages.

The Portuguese voyages along the west coast of Africa, initiated by Prince Henry, the navigator, must be regarded as among the first fruits of the Renaissance, and the prelude to the great maritime discoveries of the 15th and 16th centuries. The views of Mela prevailed in Portugal, whereas those of Ptolemy were elsewhere supreme. By the time of Prince Henry's death in 1460, the Portuguese had reconnoitered the coast of Africa for 1,700 miles, and Bartholomew Diaz reached and doubled the Cape of Good Hope in 1486. This most successful voyage produced an immense sensation. A deathblow was given to Ptolemy's view that the Indian Ocean was an inclosed sea; the fiery zone of the ancients had been crossed; the southern temperate zone of Aristotle, Strabo, and Mela had been reached, and it was inhabited. The air was filled with the noise of discovery. A few years later Columbus made his ever famous voyage across the Atlantic; Vespucci announced the discovery of a new world in the Southern Hemisphere, *a fourth part* unknown to the ancients. The Portuguese sailed to India, the Spice Islands, and even China by way of the cape. From a peak in Darien, Balboa beheld a boundless ocean beyond the new-found lands in the west, and in 1520 Magellan passed into and crossed this great ocean, which he called the Pacific, thus completing the first circumnavigation of the world. These great voyages doubled at a single bound all that was previously known of the earth's surface. The sphericity of the earth, the existence of antipodes, were no longer scientific theories, but demonstrated facts. The loss or gain of a day in sailing round the world, together with a multitude of other unfamiliar and bewildering facts, struck the imagination, and altogether the effect of these startling events was without parallel in the history of the world. The solid immovable earth beneath men's feet was replaced by the mental picture of the great floating globe swung in space, supported by some unseen power. This grand conception can be traced in the literature of the succeeding century. Bacon and Milton had the image of the huge spinning globe continually before them, and Shakespeare's spirit seemed

> "To reside
> In thrilling region of thick-ribbed ice;
> To be imprison'd in the viewless winds
> And blown with restless violence round about
> The pendent world."

Although many voyages were soon undertaken to the Arctic, centuries passed away before maritime exploration was directed toward the

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* See Murray, "The Discovery of America by Columbus," *Scot. Geogr. Mag.*, 1893, vol. IX, p. 561.

Antarctic regions. The unknown lands of Ptolemy and other geographers, though now cut off from the northern continents, still retained their place on charts down to the second voyage of James Cook, under the names of Southern Ethiopia, the Austral Continent, Magellanica, Regio Brasilio, and Regio Patalis. On a globe dated 1534, which I lately examined at Weimar, mountains, lakes, and rivers are shown on a large extent of land in the Pacific, stretching toward the South Pole. In 1642 Tasman showed that Australia and Van Dieman's Land were surrounded by the ocean to the south, but the west coast of New Zealand, which he visited, was believed to be a part of the great southern continent, and this was held by some geographers of the eighteenth century to extend as far east as the island of Juan Fernandez, to be greater in extent than the whole civilized part of Asia, and to contain 50,000,000 inhabitants. Here is a part of the dedication of a collection of voyages, published in 1770 by a former hydrographer of the Navy:

"Not to him—who infatuated with female blandishments, forgot for *what* he went *abroad* and hastened back to amuse the European world with stories of *enchantment* in the New-Cytheria; BUT to—the man—who *emulous* of Magalhanes, and the heroes of former times, *undeterr'd* by difficulties, and *unseduc'd* by pleasure, shall *persist* through *every* obstacle, and not by chance, but by virtue and good conduct *succeed in establishing an intercourse with* a southern continent, this historical collection of former discoveries in the South Pacific Ocean is presented by Alexander Dalrymple."

About this time a French navigator reported the discovery of land to the southeast of the Cape of Good Hope, and a French expedition under M. de Kerguelen was sent out in 1772 to explore it. Kerguelen sighted land with high mountains in latitude 49° south and longitude 69° east, sent a boat on shore, and rather precipitately concluded that he had discovered the great southern continent. On his return to France he was hailed as a second Columbus, but on being sent out a second time to complete his discovery, the supposed southern continent turned out to be the almost barren island which now bears Kerguelen's name.

During his first expedition James Cook showed that New Zealand was an island, and that there was no southern continent in the Pacific north of the parallel of 40° south. Cook's second expedition in 1772 was undertaken with the express purpose of settling once for all this question of a southern continent, and he crossed the whole southern ocean in such a manner as to leave no room for doubt that, if such a continent did exist, it must be situated within the Antarctic Circle, and must be covered with perpetual snow and ice.

Cook reached latitude 71° 10′ south, in longitude 106° 54′ west, and here he probably saw the ice-barrier and mountains beyond. He believed there was a tract of land toward the South Pole extending

farther north in the Atlantic and Indian oceans than elsewhere, and says:

"It is true however that the greatest part of this southern continent (supposing there is one) must lie within the Polar Circle, where the sea is so pestered with ice that the land is thereby inaccessible. The risque one runs in exploring a coast in these unknown and icy seas is so very great that I can be bold enough to say that no man will ever venture farther than I have done, and that the lands which may lie to the south will never be explored. Thick fogs, snowstorms, intense cold, and every other thing that can render navigation dangerous, must be encountered, and these difficulties are greatly heightened by the inexpressibly horrid aspect of the country, a country doomed by nature never once to feel the warmth of the sun's rays, but to lie buried in everlasting snow and ice. The ports which may be on the coast are, in a manner, wholly filled up with frozen snow of vast thickness; but if any should be so far open as to invite a ship into it, she would run a risque of being fixed there for ever, or of coming out in an ice island. The islands and floats on the coast, the great falls from the ice-cliffs in the port, or a heavy snowstorm attended with a sharp frost, would be equally fatal."

Two navigators have however ventured farther than Cook. Weddell in 1823 penetrated to 74° south, but saw no land. Sir James Clark Ross in 1841 and 1842 reached the seventy-eighth parallel, and discovered Victoria Land. These three explorers, Cook, Weddell, and Ross, are the only ones who have passed beyond the seventieth parallel of south latitude.

A great many expeditions have sailed between the sixtieth and seventieth parallels, and nearly all of them have discovered land in these southern latitudes. In 1819 Smith discovered the South Shetlands to the south of Cape Horn, and soon afterward a brisk seal fishery among English and American sealers sprang up in these waters, the seal skins bringing a high price in China. Bellingshausen discovered the islands of Alexander and Peter the Great; D'Urville discovered Adélie Land; the United States exploring expedition discovered Wilkes' Land; Powell discovered the South Orkneys; Biscoe discovered Enderby's Land; Balleny discovered the Balleny Islands and Sabine Land, and Dallman more recently discovered Kaiser Wilhelm Islands and Bismarck Strait to the north of Graham's Land.

The greatest, the most successful and most important expedition to the Antarctic was, however, that of Sir James Clark Ross, just referred to, between the years of 1839 and 1843. He has furnished more trustworthy information than all the preceding and succeeding expeditions put together. The chief object of the expedition was to make magnetic observations, and these were carried out with marked success. Ross, who had previously planted the flag of his country on the north magnetic pole, even sailed within 160 miles of the south magnetic pole. During the expedition Ross threw a flood of new light on the physical and biological conditions of the Antarctic. He discussed his meteorological observations, and pointed out the permanently low atmospheric

pressure of the Southern Hemisphere; he took surface and deep-sea temperatures with much regularity; he became a pioneer in accurate deep-sea sounding and deep-sea dredging; he recognized that the animals from deep water were almost identical with those found at similar depths by his uncle in the Arctic, and he prophesied that a nearly uniform low temperature would ultimately be found everywhere in deep water, and that living animals would be found at the greater depths all over the floor of the ocean. In the account of his voyage we find the best expression of all the anxieties, the dangers, the sufferings, the charms and fascination, which accompany work in these bitter, appalling, and magnificent realms of ice, where snow-storms, fogs, and gales alternate with brilliant sunshine.

In January, 1841, after passing heavy pack ice far to the south of New Zealand, Ross discovered Victoria Land, consisting of mountain ranges from 7,000 to 12,000 and 15,000 feet in height. To the east he found open navigable water with off-lying islands, on two of which—Possession and Franklin islands—he landed. This bold coast was traced for 500 miles to the south, where it terminated, in latitude 78° south, in the volcanic cones of Mounts Erebus and Terror, Mount Erebus at the time vomiting forth flame and lava from an elevation of 12,000 feet. Glaciers descending from the mountain summits filled the valleys and bays of the coast, and projected several miles into the sea. It was impossible to enter any of the indentations or breaks on the coast, where, in other lands, harbors usually occur. On some days the sun shone forth with great brilliancy from a perfectly serene and clear sky of a most intense indigo blue, and the members of the expedition gazed with feelings of indescribable delight upon a scene of grandeur and magnificence beyond anything they had before seen or could have conceived.

From the eastern foot of Mount Terror, Ross found a perpendicular wall of ice from 150 to 200 feet in height, extending away to the east, through which, as he says, there was no more chance of sailing than through the cliffs of Dover. He traced this ice barrier in an east and west direction for 300 miles; and within a mile of it he obtained a depth of 260 fathoms, with a fine soft mud at the bottom. In the following season Ross was not so successful; for weeks he was a prisoner in the pack ice. Still, he reached the ice barrier again in latitude 78° 10′ south, a little to the east of his position in the previous year, but no new land was discovered. In the third season Ross made explorations among the islands to the south of Cape Horn, landing on Cockburn Island, but his attempts to follow in the track of Weddell were unsuccessful, owing to the heavy pack ice encountered throughout the season.

It must be remembered that Ross was the only Antarctic explorer provided with ships properly strengthened and fortified, and this probably accounts for his remarkable performances in the pack ice.

The oftener I read the account of this magnificent expedition, the more do I wish that another such commander, and another such expedition, might be sent out from this country, provided with steam power and all the appliances for investigation which the experience of the past fifty years would be able to suggest. With the same amount of good luck, priceless additions would certainly be made to human knowledge.

The *Challenger* was the first, and up to the present time the only steam vessel which has crossed the Antarctic Circle. She was wholly unprotected for ice work. Her contributions towards the solution of Antarctic problems belong for the most part to the deeper regions of the Antarctic Ocean. During last year, some interesting observations have been furnished by the Scotch and Norwegian whalers, who visited the seas and islands immediately to the south of Cape Horn.

After this brief review of Antarctic exploration we may ask: What is the nature of the snow and ice-covered land observed at so many points towards the South Pole? Is there a sixth continent within the Antarctic Circle, or is the land nucleus, on which the massive ice cap rests, merely a group of lofty volcanic hills? This is a question still asked and answered differently by naturalists and physical geographers. To my mind there seems to be abundant evidence that there exists in this region a vast extent of true continental land, the area of which is greater than that of Australia, or nearly 4,000 000 square miles. Of all the bold southern explorers Ross and D'Urville are the only two who have set foot on land within the Antarctic Circle. I can find no record of any ship having come to anchor within the Antarctic area, or indeed south of the latitude of 60° south, although Ross met with shallow enough soundings off Possession Island, and Wilkes found 19 fathoms in Piner's Bay, Adélie Land.

Ross reports the rocks of Possession, Franklin, and Cockburn Islands, on which he landed, to be of volcanic origin, and in his dredgings to the east of Victoria Land in depths from 200 to 400 fathoms, he likewise procured many volcanic rocks along with some fragments of a gray granite.* All explorers report the islands to the south of Cape Horn to be composed of volcanic rocks, but the recent soundings in this vicinity by Mr. Bruce indicate the presence of metamorphic and even sedimentary rocks, and Dr. Donald has brought home some interesting tertiary fossils collected last year on Seymour Island by a Norwegian whaler.† We have thus very good reasons for assuming that

*McCormick compares the mountains of Victoria Land to those of Auvergne in France. His sketches are very different from those of Davis, in showing much more geological structure and much less snow and ice. See R. McCormick, "Voyages of Discovery in Arctic and Antarctic Seas;" London, 1884, vol. I.

†Messrs. G. Sharman and E. T. Newton, F. R. S., palæontologists to the Geological Survey, state that the nine fossils from Seymour Island are of much interest from a geological point of view. They are weathered and somewhat denuded, indicating, probably, a long exposure upon a seashore. They belong to the following well-known forms: Five to *Cucullæa*, one to *Cytherea*, one to *Natica*, and two are pieces of conif-

in the Antarctic, facing the great Pacific Ocean, there is a chain of active and extinct volcanic cones, rising in Mounts Erebus and Melbourne to 12,000 and 15,000 feet, similar to, or rather a continuation of, that vast chain of volcanoes which more or less completely surrounds the whole Pacific, facing, so to speak, the circle of continental land looking out on that great ocean basin.

When we remember that their ships were wholly unprotected for ice, the voyages of D'Urville and Wilkes to the Antarctic Circle south of Australia must be regarded as plucky in the extreme. At Adélie Land D'Urville passed through the vast tabular icebergs and reached open water within a few miles of the land, which at that point rose to a height of 2,000 and 3,000 feet. Here the members of the expedition landed on a small island about 600 yards from the mainland. The rocks are described as granite and gneiss, and from the description of their hardness there can be little doubt that the fundamental gneiss so characteristic of continental land was here exposed. Wilkes was unable to reach land, but in the same locality he found very shallow water, and landed on an iceberg covered with clay, mud, gravel, stones, and large boulders of red sandstone and basalt, 5 or 6 feet in diameter.

There is another way in which a great deal may be learned concerning the nature of Antarctic land. During the *Challenger* expedition, transported fragments of continental rocks were never found toward the central portions of the great ocean basins in tropical and sub-tropical regions. The only rocks dredged from these areas were fragments of pumice or angular rock fragments of volcanic origin. In the Central Pacific, however, as the fortieth parallel of south latitude was approached—therefore just beyond the limit to which Antarctic icebergs have been observed to drift—a few rounded fragments of granite and quartz were dredged from the bottom of the sea; similar fragments were obtained in the South Atlantic in high latitudes, and as the *Challenger* proceeded toward the Antarctic Circle in the South Indian Ocean these fragments of continental rocks increased in number till, at the most southerly points reached, they, along with the mineral particles and muddy matter derived from continental land, made up by far the larger part of the deposit. These fragments consisted of granites, quartziferous diorites, schistoid diorites, amphibolites, mica schists, grained quartzites, sandstone, a few fragments of compact limestone, and partially decomposed earthly shales. These lithological types are distinctly indicative of continental land, and remembering what has just been said as to their distribution, it seems wholly unnecessary to refute the suggestion that these fragments may have been transported from the northern continents.

erous wood. All these genera have a wide distribution in time, and consequently tell little as to the age of the fossils; but some of the shells present so close a resemblance to species known to occur in Lower Tertiary beds in Britain, and to others of about the same age, recorded by Darwin and Baker, from Patagonia, as to make it highly probable that these Antarctic fossils are likewise of Lower Tertiary age.

Glauconite is another mineral which was procured in the blue muds near Antarctic land. This mineral fills the shells of foraminifera and other calcareous organisms, and has been found in the muds along nearly all continental shores where the débris of continental rocks makes up the greater part of the deposit. Glauconite is now in process of formation in all these positions, but it is apparently wholly absent from the pelagic deposits of the great ocean basins far from continental land, as well as from the deposits around volcanic islands. Its presence in the blue muds of the far south is therefore most suggestive of an Antarctic continent.

When we come to estimate the extent of this sixth continental area, greater difficulties are presented. A knowledge of the depths of the surrounding ocean would enable the outlines to be drawn with great exactitude, but unfortunately the positions where accurate soundings have been taken are few and far between. In the South Pacific, South Atlantic, and South Indian oceans, between the latitudes of 30° and 50° south, we have most excellent lines of soundings right round the world and in these latitudes the average depth of the ocean is over 2,300 fathoms, or about 2½ miles.* Between the latitudes of 50° and 65° south, the indications we possess appear to show a gradual shoaling, with an average depth of about 1,700 fathoms, or nearly 2 miles. I have been criticised for showing on bathymetrical charts a great depth in the Southern Ocean to the southwest of south Georgia. This has been done because of a sounding by Ross, who paid out 4,000 fathoms of line at this spot without finding bottom. Ross knew perfectly well how to take deep-sea soundings, and his observation seems to show that the ocean is here deeper than 4,000 fathoms, and this may well be accepted till disproved by more trustworthy results; besides the temperature of the deep water to the east of South America points to a great depth in this region. The depths obtained by the *Challenger* in the neighborhood of the Antarctic Circle were 1,675, 1,800, and 1,300 fathoms, and judging from the nature of the deposits I think all these were within 100 or 200 miles from land. Wilkes obtained depths of 500 and 800 fathoms about 20 or 30 miles from the shore of Adelie Land, and Ross obtained many soundings of from 100 to 500 fathoms all over a great bank extending 200 miles to the east of Victoria Land; similar depths have been found to extend to some distance to the east of Joinville Land to the south of Cape Horn. We have no trustworthy indications of ridges, barriers, or banks extending far northwards from Antarctica. It is, therefore, most probable that the northern continents are everywhere cut off from the Antarctic land mass by a depth approaching to, if not exceeding, 2 miles. Taking all these indications into consideration I have shown on the map what I believe to be the probable position and extent of Antarctica. Like other continents it would appear to have mountain ranges with volcanoes facing one ocean, and lower hills and

* See accompanying map of South Polar area.

great lowland plains stretching toward the other ocean basins. In order to account for the distribution of terrestrial organisms in the Southern Hemisphere, some naturalists believe that there must have been in recent geological times a great extension of Antarctica towards the tropics. However this may be, all will agree that a very necessary preliminary to any profitable discussion of so difficult a subject must be a fuller knowledge of the present conditions that prevail throughout the Southern Hemisphere, such as a new expedition alone can be expected to supply.

All observers agree in representing the great Antarctic land mass to be buried beneath a heavy capping of perpetual ice and snow. The nucleus of rock is only revealed in off-lying islands, or on the face of high and bold escarpments. The outlines and larger features of the mountain ranges are not obliterated in the highland near the coasts at all events, for peak after peak with varied contours are seen to rise, one behind the other, towards the interior.

The snow and ice which descend from the steep seaward face of the Admiralty and Prince Albert ranges of Victoria Land, while filling up the valleys and bays, do not present an inaccessible face of ice at all parts of the coast, although this is often stated to be the case. Ross himself says: "Had it been possible to have found a place of security (for the ships) upon any part of this coast, where we might have wintered in sight of the brilliant burning mountain, and so short a distance from the magnetic pole, both of these interesting spots might easily have been reached by travelling parties in the following spring." McCormick, a member of Ross's expedition, recommends Macmurdo Bay, at the foot of Mount Erebus, as a place where winter quarters might be found, and hints that there would be no difficulty in ascending and travelling over the land.

The ice and snow however which form on the slopes of the mountain ranges facing the interior of Victoria Land descend to the lower reaches of the continent, where they accumulate in vast undulating fields and plains, hundreds of feet in thickness, and ultimately this great glacier or ice cap is pushed out over all the lowlands into the ocean, forming there the true ice barrier, a solid perpendicular wall of ice, probably from 1,200 to 1,500 feet in thickness, rising from 150 to 200 feet above, and sinking 1,100 to 1,400 feet below the level of the sea. When the forefronts of this great creeping glacier are pushed into depths of about 300 or 400 fathoms, large stretches are broken off and float away as the oft-described, perpendicular-faced, horizontally-stratified, table-topped icebergs of the Antarctic and Southern oceans, which may be miles in length, and usually float from 150 to 200 feet in height above the sea surface.*

* A floating iceberg will have 89·6 per cent of its volume immersed if it have the same temperature and consistency throughout. The upper layers of these ice islands are however much less dense than the deep-blue lower layers, and therefore it is

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SOUTH POLAR REGIONS, SHOWING ROUTES OF PRINCIPAL EXPLORERS.
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No sooner do these great ice islands—these majestic and sublime sentinel outposts—of Antarctica sail forth on their new career, than they collide the one with the other; the fragments of impact are scattered over the surface of the ocean, and, with similar fragments derived from the steeper land slopes, with salt-water ice, and accumulations of snow, they form what is known as the *pack*. This pack, when heavy and closely set, has been erroneously called by Wilkes and other writers the ice barrier—a name which should only be used to designate the solid continuous ice wall that is pushed into the sea from the central regions of the continent, such as that along which Ross sailed for 300 miles.

Waves dash against the vertical faces of the floating ice-islands as against a rocky shore, so that at the sea level they are first cut into ledges and gullies, and then into caves and caverns of the most heavenly blue,* from out of which comes the resounding roar of the ocean, and into which the snow-white and other petrels may be seen to wing their way through guards of soldier-like penguins stationed at the entrances. As these ice islands are slowly drifted by wind and current to the north, they tilt, turn, and sometimes capsize, and then submerged prongs and spits are thrown high into the air, producing irregular pinnacled bergs higher, possibly, than the original table-shaped mass. As decay proceeds, the imprisoned bowlders, stones, and earth are deposited over the ocean's floor as far as sub-tropical regions.

The late Mr. Croll used to speak of an accumulation of ice and snow at the South Pole 10 and even 20 miles in thickness; but from all we know of the properties of ice, and the relation of its melting or freezing point to temperature and pressure, it is highly improbable that such a thickness of ice will be found on any part of the Antarctic continent. If the snow cap rests on rock of a temperature half a degree below the freezing point, then the greatest thickness of ice formed on the continent would not likely exceed 1,600 or 1,800 feet, and this appears to be just a little more than the greatest thickness of the great ice barrier when it is floated off into the ocean as ice islands. This may possibly represent the greatest thickness that can be formed under existing con-

most probable that the height above water is about one-seventh of the total thickness of the berg.—*See* Murray, "The Exploration of the Antarctic Regions," *Scot. Geogr. Mag.*, 1886, vol. II, p. 553.

* The deep blue color is due to the fact that all the air has been expelled from the deeper parts of the ice cap by the constant melting and regelation which takes place throughout the whole mass as it moves over the land. When a cannon ball was fired into this azure-blue ice the ball did not penetrate, but large masses of ice fell away, the fractures having a conchoidal appearance like glass. When a ball was fired into the upper areolar white layers of a table berg it penetrated without producing any visible effect. Fragments of the white areolar layers were subjected to pressure and impact on board ship, and it was observed that these fragments could be easily deformed, while fragments of the transparent azure-blue ice behaved quite differently under the same tests, resembling a purely crystalline substance.

ditions.* A party of well-equipped observers—who should spend a winter on the Antarctic continent—would doubtless bring back valuable information for the discussion of this interesting problem, such as serial temperatures from borings in the ice cap, both vertically and horizontally, the temperature of the earth's surface beneath the ice, whether or not water runs away from under the glaciers, as well as observations concerning the appearance of the upper surface of the ice fields and the motion of the ice over the land.

Our knowledge of the meteorology of the Antarctic regions is limited to a few observations during the summer months in very restricted localities, and is therefore most imperfect. One of the most remarkable features in the meteorology of the globe is the low atmospheric pressure, maintained in all seasons, in the Southern Hemisphere south of latitude 40° south, with its inevitable attendant of strong westerly winds, large rain and snow-fall, all round the globe in these latitudes. The observations hitherto made point to the existence over certain parts of these latitudes of a mean pressure of 29·00 inches and under,—as for example to the southeast of the Falkland Islands and to the southeast of New Zealand.

On the other hand, in the Arctic regions there is in the winter months no such system of low pressure in similar latitudes, but instead there are two systems of low pressure, having a mean of 29·50 inches, which are absolutely restricted to the northern portions of the Atlantic and Pacific oceans. Over the rest of the Arctic regions proper the mean atmospheric pressure exceeds 30·00 inches, being, roughly speaking, about the same as the mean pressure of London. In accordance with this distribution of pressure, observations show that northerly winds immensely preponderate over Arctic and sub-Arctic regions. The large number of meteorological observations made during the present century in the high latitudes of the Northern Hemisphere place these facts in the clearest light, and they are admirably represented by Dr. Buchan in his new isobaric charts which accompany the *Challenger* report.

In the Northern Hemisphere the land almost completely surrounds the

* See Murray *op. cit.*, p. 535: 1886. The motion of glaciers is often compared to that of rivers and of viscous bodies; but these comparisons are not strictly correct, and may sometimes be misleading. The peculiarity of ice motion and its erosive power appear to be largely due to the fact that its melting or freezing point varies with temperature and pressure. The pressure being unequally distributed throughout the glacier, minute crystals of ice are melted where the pressure is greatest; the resulting water occupying less space, regelation at once takes place, and where the ice is wholly compact and crystalline pressure is exerted in all directions, motion taking place in the path of least resistance. The immense thickness of ice sometimes invoked does not seem necessary to account for the erosive effects produced by glaciers. The stratified appearance of the southern icebergs is evidently due to the constant melting and regelation which go on throughout the ice cap; in the deeper parts of the bergs these layers are not thicker than wafers, and where the ice is wholly crystalline the layers disappear altogether.

Arctic Ocean; in the Southern Hemisphere the open ocean completely surrounds the Antarctic continent, and this open ocean carries with it the low barometric pressure all round. Now, if the low pressure still further deepened with increase of latitude towards the South Pole, it is certain that the prevailing winds over all these high latitudes would be northwesterly and northerly. But the observations made by Ross, the *Challenger*, and more recently, in latitudes higher than 60° south, by the Dundee whalers and others, quite unanimously tell us that in these high southern latitudes the predominating winds are southerly and southeasterly. Thus, during the winter of 1892–'93, in latitudes higher than 60° south, half of the whole winds recorded by the *Diana* were south, southeast, and east, being directions opposite to the winds which would certainly prevail if pressure diminished steadily to the South Pole. Such surface currents as have been observed in the Antarctic Ocean come also from south and southeast.

All the teaching of meteorology therefore indicates that a large anti-cyclone with a higher pressure than prevails over the open ocean to northwards overspreads the Antarctic continent. While this anti-cyclonic region may not be characterized by an absolutely high pressure at all seasons, it must be high relatively to the very low pressure which prevails to the northward. The southerly outflowing winds which accompany this anti-cyclone will be dry winds and attended by a small precipitation. It is probable that about 74° south the belt of excessive precipitation has been passed, and it is even conceivable that at the pole precipitation might be very little in excess of, or indeed not more than equal to, the evaporation. Even one year's observations at two points on the Antarctic continent might settle this point, and enable us to form a tolerably complete idea of the annual snow-fall and evaporation over the whole continent. An approximate estimate might then be given of the annual discharge from the solid glacier rivers into the surrounding ocean. Indeed it is impossible to over-estimate the value of Antarctic observations for the right understanding of the general meteorology of the globe.

Not less interesting than the meteorology of the land area is that of the ocean in southern latitudes. In the neighborhood of the Antarctic Circle the temperature of the air and sea surface is, even in summer, at or below the freezing point of fresh water. A sensible rise takes place about the sixtieth parallel, and a temperature of 38° F. has been recorded in that latitude in March for both the air and sea surface. The general result of all the sea temperatures observed by Cook, Wilkes, Ross, and the *Challenger* in the Antarctic Ocean shows that a layer of cold water underlies in summer a thin warm surface stratum and overlies another warm but deeper stratum towards the bottom. The cold stratum extends like a wedge northwards for about 12°. At depths between 50 and 300 fathoms at the southern thick end of the wedge the temperature is 28° F., and at the northern thin end of the wedge it increases to about 32.5°

at 80 fathoms. The surface layer ranges from 29° in the south to 38° in the north, and the deeper bottom layers range from 32° to 35°.

Mr. Buchanan found that the density of the cold layer, and indeed of all the deeper waters, was higher than that of the surface, and his admirable researches on the effects produced by freezing sea water, appear to give a satisfactory explanation of the effect of these phenomena on the distribution of temperature in this ocean. It has been found that sea water on freezing is divided into two saliniferous parts, one solid, which is richer in sulphates, and one liquid, which contains proportionally more chlorides than the parent sea water.* The liquid brine thus produced is denser, and sinks into the underlying water, thus rendering the deeper water more saline and at the same time lowering its temperature. In a basin isolated from general oceanic circulation, like the Norwegian basin of the Arctic regions, there is produced in this way an uniform temperature of about 29° F. in all the deeper waters, but no trace of this state of matters is found in the Antarctic. On the contrary, at the greater depths a temperature is found somewhere between 32° and 34° F. as far south as the Antarctic circle, and not therefore very different from the temperature of the deepest bottom water of the tropical regions of the ocean.

The presence of this relatively warm water in the deeper parts of the Antarctic Ocean may be explained by a consideration of general oceanic circulation. The warm tropical waters which are driven southwards along the eastern coasts of South America, Africa, and Australia, into the great all-encircling Southern Ocean, there become cooled as they are driven to the east by the strong westerly winds. These waters on account of their high salinity, can suffer much dilution with Antarctic water, and still be denser than water from these higher latitudes at the same temperature. Here again, the density observations indicate that the cold water found at the greater depths of the ocean probably leaves the surface and sinks toward the bottom in the Southern Ocean between the latitudes of 45° and 56° south. These deeper, but not necessarily bottom, layers are then drawn slowly northward toward the tropics to supply the deficiencies there produced by evaporation and southward-flowing surface currents, and these deeper layers of relatively warm water appear likewise to be slowly drawn southwards to the Antarctic area to supply the place of the ice-cold currents of surface water drifted to the north. This warm underlying water is evidently a potent factor in the melting and destruction of the huge table-topped icebergs of the southern hemisphere. While these views as to circulation appear to be well established, still a fuller examination of these waters is most

* Petterssen has shown that sea ice expands irregularly with heat, and that the latent heat is abnormal, being less than that of pure ice. He also found that the chemical composition of the brines formed in Arctic seas by the freezing of ice out of a limited quantity of water is different from that of sea water itself. There is, however, no certainty that this behavior of the ice and free sea water is due to the formation of the hypothetical cryohydrates of Guthrie.

desirable at different seasons of the year, with improved thermometers and other instruments. Here, again, a new Antarctic expedition would supply the knowledge essential to a correct solution of many problems in Oceanography. Ross describes a strong tidal current and rip between Possession Island and the mainland of Victoria, but on the whole, we have very little information concerning the tides and surface currents in the Antarctic.

No land animal, and no trace of vegetation, not even a lichen or a piece of seaweed, has been found on land within the Antarctic circle. On Cockburn Island, in latitude 64° south, Hooker collected twenty cryptogamic species, three of them seaweeds, and this may be regarded as not far from the southern limit of terrestrial vegetation. The fossils and fossiliferous beds above referred to distinctly indicate the existence of more genial conditions within the Antarctic in past geological times, and should be fully explored.

When we turn to the waters of the Antarctic Ocean, we find at the present time a great profusion of life, both animal and vegetable. During the *Challenger* expedition, myriads of minute spherical tetrasporæ were observed to give the sea a peculiar green color over large areas. Diatoms were frequently in such enormous abundance, that the tow nets were filled to the brim with a yellow-brown slimy mass, with a distressing odor, through which various crustaceans, annelids, and other animals wriggled.

As these marine algæ are the primary source of food in the sea, their great development in the Antarctic Ocean leads to a corresponding abundance of animals. Occasionally vast quantities of Copepods Amphipods, and Schizopods were observed to give the ocean a dull red color, and the more delicate tow nets were at such times so filled with these animals, that they occasionally burst on being hauled on board ship. These small crustaceans are in turn the chief food of the fishes, penguins, seals, and whales, which abound in the waters of the Great Southern Ocean.

Organisms such as the diatoms and radiolaria, which secrete silica, and the foraminifera and pteropods, which secrete carbonate of lime, are, on account of their distribution, the most interesting of all the pelagic creatures captured in the surface and sub-surface waters of the ocean. Near Antarctic land the deposits at the bottom of the sea are, as already stated, mostly made up of rock fragments and detritus from the snow-clad Antarctic continent. A little to the north the number of these particles decreases, and they are largely replaced by the dead frustrules of diatoms and radiolaria, and then we find a pure white siliceous deposit at the bottom, which is called a diatom ooze. Still farther to the north, when the influence of the warm northern currents commences to be felt, the diatoms are largely replaced on the surface by the calcareous shells of foraminifera and pteropods, and at the bottom of the sea in these latitudes the diatom ooze gives place to a

pinkish-white globigernia ooze, composed chiefly of carbonate of lime. Still farther to the north, about the latitude of 40° south, the sea is often about 3 miles in depth, and in such depths where far removed from continental land, the calcareous shells are for the most part dissolved, and there is a very remarkable deposit at the bottom, composed of a fine red clay, manganese nodules, zeolitic crystals, magnetic and metallic spherules of extra-terrestrial origin, thousands of sharks' teeth, and the remains of whales and other cetaceans. In these red clay areas the trawl brought up in a single haul over 1,500 sharks' teeth, some of them as large as—and not to be distinguished from—the specimens of *Carcharodon* of Tertiary age; associated with these teeth were 50 or 60 earbones of ziphiod whales and other cetaceans.* From a careful consideration of all the conditions, it seems to me that deposition is, in these places, at the minimum, and that since Tertiary times there may not have been over a few inches of deposit laid down in these red clay areas. A new expedition might thoroughly explore one of these peculiar and instructive deposits.

All over the floor of the Antarctic Ocean there is a most abundant fauna, apparently more abundant and more peculiar than in any other region of the ocean's bed. In one haul made by the *Challenger* in a depth of 2 miles in latitude 47° south, the trawl brought up (excluding protozoa) over 200 specimens belonging to 89 species of animals, of which 73 were new to science, including representatives of 28 new genera. This and similar trawlings show a larger number of individuals, genera, and species than any single haul from similar depths in other regions of the oceans, and I am inclined to think this is intimately connected with the large number of surface creatures which are killed in these latitudes by the mixing of waters from the tropics and waters from the Antarctic; for these organisms, on falling to the bottom, afford a larger supply of food to deep-sea animals here than in other localities.

The following table exhibits the total result of the *Challenger's* 9 trawlings and dredgings south of the forty third parallel, in depths greater than 1,200 fathoms; 830 animals were captured (excluding the protozoa) belonging to 398 species, of which 326, or nearly all those described, were new to science. Of these 162 new species and 30 new genera, were not obtained in any other region of the bed of the ocean. Among these were 8 new genera and 56 new species of echinoderms, many of them exhibiting marked peculiarities.† Many other forms, such as some species of serolis among the crustacea, are limited to the deep water of the Southern Hemisphere. The absence of some groups, such as the brachyura, in all these dredgings is likewise suggestive.

* See Murray and Renard, *Challenger* Report on Deep-Sea Deposits, 1891, p. 360.

† Namely *Thaumatocrinus*, *Chitonaster*, *Ophioplinthus*, *Ophiocymbium*, *Spatagocystis*, *Echinocrepis*, *Genicopatagus*, and *Scotoanassa*. Alexander Agassiz says: "The slipper-shaped *Echinocrepis* and the *Galerites*-like *Urechinus* (found only in the deep water of the Antarctic area), remind us of types which flourished in the Cretaceous seas,"

*Animals (excluding the Protozoa) obtained in the trawl and dredge by the Challenger expedition towards the Antarctic regions in depths greater than 1,200 fathoms.**

Latitude.	Station.	Depth in fathoms.	Number of specimens.	Number of species.	Number of new species.	Number of new genera.
Between 43° and 50° south..	146	1,375	200	78	66	17
	147	1,600	200	89	73	23
	159	2,150	20	10	7	4
	160	2,600	50	30	25	10
Between 50° and 60° south..	157	1,950	150	79	69	25
	158	1,800	70	45	33	13
Between 60° and 65° south..	152	1,260	20	12	10	4
	156	1,975	100	37	32	13
South of 65° south............	153	1,675	20	18	11	5
	....	....	830	398	326	119

* One hundred and sixty-two new species and 30 new genera were not obtained outside this Antarctic area during the cruise.

It is most probable, indeed almost certain, that the floor of the ocean, as well as all pelagic waters, have been peopled from the shallow waters surrounding continental land; and here in the deep waters of the Antarctic we appear to have very clear indications of the existence of the descendants of animals that once inhabited the shallow water along the shores of Antarctica, while in other regions of the ocean the descendants of the shallow water organisms of the northern continents prevail. This is a subject of great interest to all biologists, and can best be studied by a more efficient exploration of these southern latitudes.

This rapid review of the present state of our knowledge concerning the Antarctic should, if in any way successful, have at the same time furnished distinct indications as to the great extent of our ignorance concerning all that obtains within the South Polar regions. It should likewise have enabled you to appreciate the great advantages which would flow from successful exploration in the immediate future.

Within the past few months I have been in communication with geographers and scientific men in many parts of the world, and among them there is complete unanimity as to the desirability, nay, necessity, for South Polar exploration, and wonder is expressed that an expedition has not long since been fitted out to undertake investigations which, it is admitted on all sides, would be of the greatest value in the progress of so many branches of natural knowledge. Prof. Neumayer, who has so long advocated South Polar exploration, says: "It is certain that without an examination and a survey of the magnetic properties of the Antarctic regions, it is utterly hopeless to strive, with prospects of success, at the advancement of the theory of the earth's magnetism." Other eminent geographers and scientific men urge the advantages which would accrue to other branches of science.*

* Prof. Alexander Agassiz writes: "I wish you the best success with your proposed Antarctic expedition. What you propose doing is the right thing to do, and the results ought to be most interesting, judging from the little we know of the few

To determine the nature and extent of the Antarctic continent; to penetrate into the interior; to ascertain the depth and nature of the ice-cap; to observe the character of the underlying rocks and their fossils; to take magnetical and meteorological observations both at sea

islands which have been hastily visited. Your scheme of having the ships kept at work, sounding, dredging, etc., while the land parties are exploring the land, is the most practical and economical way of carrying on such an expedition. It has always seemed to me such a waste of time and money to have the ships and their crews wait on the landsmen."

Prof. Ernest Haeckel writes:* "I have heard with great interest that England has the design of setting on foot a great scientific expedition for the exploration of the Antarctic Ocean. The task is in fact as interesting as it is pressing and important. It is remarkable how much money and how many lives have been offered by Europe and North America for North Polar expeditions, while the much less known South Pole has seemed almost forgotten since Ross's time. And how many great and important problems await solution there! The British nation seems to me called upon before all others to carry out this great task, and to send a ship for several years (including wintering at a station) to the South Polar Sea. The fruits of such an expedition would certainly form a worthy sequel to those which you have attained through the incomparable *Challenger* expedition with its wealth of results. It would lay the foundation for all time. I hope and wish from my heart that the English Government views it in this light, and will grant the large supplies necessary for this expedition. I send you my best wishes for the speedy completion of the concluding volume of the great *Challenger* work. This 'standard work' will remain for all time the foundation for all biological and thalassographical investigations, in relation to Plankton and Benthos alike, especially of the deep sea. The thorough investigation of the Antarctic Ocean with its fauna and flora seems to me a necessary supplement to the *Challenger* work."

Prof. F. E. Schultze writes:* "You wish for my opinion on the subject of a more extensive exploration of the Antarctic region. I believe I shall be in agreement, not only with all representatives of physical geography, but especially with all the biologists in the world, when I say that there is no region of the surface of our globe which is so little known, but so much deserves a thorough investigation as precisely this of the Antarctic. Allow me also to call your attention to the fact that, of all the oceans, the southern and central part of the Indian Ocean has hitherto been least explored, and that therefore it might be advisable, if opportunity offered—say, during a winter—to make an excursion to the central part of the Indian Ocean. In the hope that to the great *Challenger* expedition may be added one similar and equally rich in results for the exploration of the Antarctic, I wish success to this important undertaking from my heart."

Prof. J. Thoulet writes: * "There is only one way in which to answer the letter you have been so good as to write to me, namely to send you my warmest encouragement to continue the great and noble task of discovering the secrets of the Antarctic regions. May you succeed in accomplishing this glorious work, which is not only scientific but also humanitarian. - - - All who are occupied on science in the whole world earnestly wish for your success. To tell you the truth, I have never been very enamoured of Arctic expeditions; the North Pole is continental, and is in consequence the domain of irregularity, and in my opinion its conquest is not worth the efforts which it has already cost. But it is quite otherwise with the Antarctic regions, which are oceanic, and therefore subject to rule. The Arctic phenomena are complications or exceptions; the Antarctic are general phenomena, and their discovery is bound to conduce to the formulation of natural laws—the final aim of science."

* Translation.

and on land; to observe the temperature of the ocean at all depths and seasons of the year; to take pendulum observations on land, and possibly also to make gravity observations at great depths in the ocean; to bore through the deposits on the floor of the ocean at certain points to ascertain the condition of the deeper layers;* to sound, trawl, and dredge, and study the character and distribution of marine organisms. All this should be the work of a modern Antarctic expedition. For the more definite determination of the distribution of land and water on our planet; for the solution of many problems concerning the ice age; for the better determination of the internal constitution and superficial form of the earth; for a more complete knowledge of the laws which govern the motions of the atmosphere and hydrosphere; for more trustworthy indications as to the origin of terrestrial and marine plants and animals, all these observations are earnestly demanded by the science of our day.

How then, and by whom, is this great work to be undertaken? I can never forget my sensations when once in the Arctic I was for several hours lost in a small boat in a fog, and at one time there seemed little chance that I would ever regain the ship. Nor again can I forget one night in the Antarctic when, with much anxiety, Capt. Nares, his officers, and men, piloted the *Challenger* during a gale through blinding snow, ice, icebergs, darkness, and an angry sea. The remembrance of these experiences makes one almost fear to encourage good and brave men to penetrate these forbidden regions. But it is not all gloom and depression beyond the Polar circles. Sunshine and lively hope soon return.

A few months ago I bade good-bye to Nansen and said, I expected within two years to welcome him on his return from the Arctic; but I expressed some doubt if I should again see the *Fram*. "I think you are wrong," was the reply; "I believe you will welcome me on this very deck, and, after my return from the Arctic, I will go to the South Pole, and then my life's work will be finished." This is a spirit we must all admire. We feel it deserves, and is most likely to command, success. All honor to those who venture into the far north or far south with slender resources and bring back with them a burden of new observations.

A dash at the South Pole is not however what I now advocate, nor do I believe that is what British science, at the present time, desires. It demands rather a steady, continuous, laborious, and systematic exploration of the whole southern region with all the appliances of the modern investigator.

This exploration should be undertaken by the Royal Navy. Two ships, not exceeding 1,000 tons, should, it seems to me, be fitted out

* It is believed that gravity determinations might be made, as well as the deposits bored into by specially constructed instruments let down to the bottom from the ships.

for a whole commission, so as to extend over three summers and two winters. Early in the first season a wintering party of about ten men should be landed somewhere to the south of Cape Horn, probably about Bismarck Strait at Graham's Land. The expedition should then proceed to Victoria Land, where a second similar party should winter, probably in Macmurdo Bay, near Mount Erebus. The ships should not become frozen in, nor attempt to winter in the far south, but should return toward the north, conducting observations of various kinds along the outer margins of the ice. After the needful rest and outfit at the Falklands or Australia, the position of the ice and the temperature of the ocean should be observed in the early spring, and later the wintering parties should be communicated with, and, if necessary, reinforced with men and supplies for another winter. During the second winter the deep-sea observations should be continued northward, and in the third season the wintering parties should be picked up and the expedition return to England. The wintering parties might largely be composed of civilians, and one or two civilians might be attached to each ship; this plan worked admirably during the *Challenger* expedition.

What, it may be asked, would be the advantages to trade and commerce of such an expedition? It must be confessed that no definite or very encouraging answer can be given. We know of no extensive fisheries in these regions. For a long time seal and sea-elephant fisheries have been carried on about the islands of the Southern Ocean, but we have no indication of large herds or rookeries within the Antarctic Circle. A whale fishery was at one time carried on in the neighborhood of Kerguelen, but this right whale, if distinct from or identical with *Balæna australis*, appears to have become nearly, if not quite, extinct. Some expressions of Ross would lead one to suppose that a whale corresponding to the Greenland right whale inhabits the seas within the Antarctic ice, but we have no definite knowledge of the existence of such a species. Although "sulphur bottoms" (*Balænoptera musculus*), "finbacks" (*Balænoptera sibbaldii*), and "humpbacks" (*Megaptera boops*) are undoubtedly abundant, they do not repay capture. Ross and McCormick report the sperm whale within the Antarctic ice, but there is some doubt on this point. Though penguins exist in countless numbers they are at present of no commercial value. Deposits of guano are not likely to be of any great extent. But it is impossible to speak with confidence on the commercial aspects of such an expedition—the unexpected may quite well happen in the way of discovery.

With great confidence, however, it may be stated that the results of a well-organized expedition would be of capital importance to British science. We are often told how much more foreign governments do for science than our own. It is asserted that we are being outstripped by foreigners in the cultivation of almost all departments of scientific work. But in the practical study of all that concerns the ocean this is

certainly not the case, for however closely we may now be pressed by some foreign nations, we have had up to the present time to acknowledge neither superiors, nor even equals in this branch of investigation, and, if we be a wise and progressive people, British science will always lead the way in this direction. When Queen Victoria ascended the throne we were in profound ignorance as to the condition of all the deeper parts of the great ocean basins; now we have a very accurate knowledge of the conditions which obtain over the three-fourths of the earth's surface covered by the waters of the ocean. This—the most splendid addition to earth-knowledge since the circumnavigation of the world—is largely due to the work and exertions of the Royal Navy in the *Challenger* and other deep-sea expeditions, and the mercantile navy in our telegraph ships.

This country has frequently sent forth expeditions, the primary object of which was the acquisition of new knowledge,—such were the expeditions of Cook, Ross, and the *Challenger;* and the nation as a whole has always approved such action and has been proud of the results, although they yielded no immediate return. Shall it be said that there is to be no successor to these great expeditions? The prestige of the navy does not alone consist in its powers of defense and attack. It has in times of peace made glorious conquests over the powers of nature, and we ask that the officers and men of the present generation be afforded the same opportunities as their predecessors There should be no observations, no experiments, no investigations, no work of any kind, no knowledge of any kind, with reference to the ocean, of which the navy has not had practical experience. And what better training for officer and man than in an expedition such as that now advocated?

A preliminary responsibility rests on the geographers and representatives of science in this country. It is necessary to show that we have clear ideas as to what is wanted, to show that a good, workable scheme can be drawn up. When this has been done it should be presented to the Government with the unanimous voice of all our scientific corporations. Then, I have little doubt that a minister will be found sufficiently alive to the spirit of the times, and with sufficient courage to add a few thousand pounds to the navy vote for three successive years, in order to carry through an undertaking worthy of the maritime position and the scientific reputation of this great Empire.

THE NORTH POLAR BASIN.*

By Henry Seebohm, F. L. S., F. Z. S.

Geography, the child of Mathematics and Astronomy, stands in the relation of mother to half a dozen other sciences, which have long ago left the parental roof to establish sections of their own. Like every other science, geography is so closely connected with, and dependent on, its allied sciences that it is impossible to treat of the one without invading the province of the others. No one supposes that the making of maps is the whole duty of the geographer. The accurate delineation of the trend of coast lines, the courses of rivers, the heights of mountains, the depths of seas, or the position of towns is only the skeleton which underlies the real science of geography.

The study of geography may be divided into various sections, but it must always be remembered that they dovetail into each other, as well as into the allied sciences, to such an extent that no hard-and-fast line can be drawn between them. The object of dividing so comprehensive a section as that of geography into sub-sections is more practical than scientific. The classification of facts is an important aid to memory, and introduces order into what might otherwise seem to be a chaos of knowledge.

The foundation of all geography is exploration; but before the traveller can do good geographical work he must acquire the necessary knowledge embraced in the science of cartography. This includes a practical acquaintance with the various instruments used in making a survey, the necessary mathematical and astronomical knowledge required for their use, and a familiarity with the accepted mode of expressing the geographical facts that may be acquired on a chart or map. Exploration may then be undertaken with some chance of ultimate success, but the object of exploration must be something more than the filling up of blanks in our maps. Many other subjects must receive attention, subjects which are collectively included in the term physical geography, but which require treatment under different heads.

* Address to the geographical section of the British Association for the Advancement of Science, at Nottingham, by the president of the section; Sept., 1893. (*The Geographical Journal*, London, October, 1893; vol. II, pp. 331–346.)

Of these the most obvious is the geographical distribution of light and heat, as well as the more fitful alterations of wind and rain with calm and drouth; in other words, the numerous causes which combine to produce climate. Meteorology or climatology, the geography of the air, is a most important branch of geography in general: and when we come to inquire into the changes which have taken place in the climate of different parts of the earth's surface, especially those which have affected the Polar Basin, we enter upon a subject which has claimed a large share of the attention of geologists, who have also made a profound study of the geographical distribution of the various kinds of rock which are found on the crust of the earth. Another sub-section of great importance is the geographical distribution of organic life. The geographical ranges of the species and genera, both of plants and animals, have become a subject of vastly increased importance since so much attention has been directed to the theory of evolution; and the paramount importance of the human race is so great that ethnological geography may fairly claim to be treated as a sub-section, apart from the study of the rest of the fauna of a country. Inasmuch as a map with the towns left out is only half a map, the geographer can not afford to neglect the races of men with which he comes in contact, nor the remains (architectural or otherwise) which existing nations have produced, or past races have left behind them.

I propose, on the present occasion, to elaborate these subjects at greater detail, and, with your permission, to take the Polar Basin as an example.

EXPLORATION OF THE POLAR BASIN.

There is only one Polar Basin; the relative distribution of land and water and the geographical distribution of light and heat in the Arctic region are absolutely unique. In no other part of the world is a similar climate to be found. The distribution of land and water round the South Pole is almost the converse of that round the North Pole. In the one we have a mountain of snow and ice covering—it may be a continent, it may be an archipelago, but in any case a lofty mass of congealed water surrounded by an ocean stretching away with very little interruption from land to the confines of the tropics. In the other we have a basin of water surrounding a comparatively flat plain of pack ice, some of which is probably permanent, but most of which is driven hither and thither in summer by winds and currents and is walled in by continental and island barriers broken only by the narrow outlets of Bering Strait and Baffins Bay and the broader gulf which leads to the Atlantic Ocean, and even that interrupted by Iceland, Spitzbergen, and Franz Josef Land. When we further remember that this gulf is constantly conveying the hot water of the tropics to the Arctic Ocean, and that every summer gigantic rivers are pouring volumes of comparatively warm water into this ocean, we can not

but admit that the climatic conditions near the two poles differ widely from each other.

In looking at a map of the Polar Basin one can not help remarking the curious fact that the North Pole is so very nearly central, and a glance at the Southern Hemisphere also shows a rough sort of symmetry in the distribution of land and water round the South Pole. It is a curious coincidence, if this be only accident.

The history of the exploration of the Polar Basin is a very long and a very tragic story. Much has been done, but much remains to do. The unexplored regions of the Polar Basin may be estimated at 1,000 000 square miles. No part of the world presents greater difficulties to the explorer. Many brave men have perished in the enterprise, and more have only just succeeded in passing through the ordeal of hunger and cold with their lives. For the most part the heroic endurance of the tortures of famine has shown a marvel of discipline, though occasionally the commanders of the expeditions have had to enforce obedience to the verge of cruelty, both in the case of men and of dogs. There are indeed a few ghastly stories, but the records of Arctic exploration are records of which any nation might be proud.

Of recent years there has been but little done to explore the unknown parts of the Polar Basin. Adventurous journeys in Central Africa and Central Asia have somewhat eclipsed the exploration of the Arctic regions. Two visits to Greenland can not however be entirely passed by in silence. In the summer of last year an expedition went to the north of Greenland under the command of Lieut. Peary, succeeded in reaching latitude 82°, and added material evidence to prove that Greenland is an island. The expedition sailed on June 6, 1891, steamed up Baffins Bay and Smiths Sound, and on July 25 dismissed the ship and established themselves in winter quarters in McCormick Bay, on the north side of Murchison Sound, in latitude 78°. They laid in a stock of game for the winter, guillemots and reindeer. A most interesting proof of the successful organization of the expedition is the fact that Mrs. Peary was one of the party, and was able to accompany her husband on his sledge trip, which started on the 18th of the following April.

It took the party a week in their dog sledges to round Inglefield Gulf, during which they discovered 30 glaciers, 10 of them of the first magnitude. During the next three months they explored the north coast of Greenland, as far east as longitude 34° west, when a great bay was reached, which they named Independence Bay, as they discovered it on July 4. The northern shore of this bay was free from snow and ice. On August 6 they regained their winter quarters in McCormick Bay. On the 8th the steamer arrived, and on the 24th they started for home, reaching Philadelphia on September 23. During the sledge journey they traveled for a fortnight at an average elevation of 8,000 feet above the sea. Besides their important additions to the map of Greenland,

the suggestive fact that the thermometer can rise to 41° F., and torrents of rain can fall in the middle of February as far north as latitude 78°, must be regarded as a valuable discovery.

It was hardly to be expected that so successful a journey should not be followed by a second attempt in order to follow up the discoveries of the first. Peary has started for the north of Greenland with a more carefully organized staff for a longer expedition, and has already reached his winter quarters. They expect to be absent two years or more. In March they hope to start for Independence Bay, which was discovered on the previous expedition, and there the party will divide, with the object of completing the survey of the coast-line of Greenland by reaching Cape Bismarck, if possible, and at the same time to explore the northern coast-line of Independence Bay, hoping that it may land them farther north than the highest point yet reached by any Arctic traveler.

In the summer of 1888 Dr. Nansen was bold enough to cross the continent of Greenland about latitude 64°, reaching an altitude of 9,000 feet, and he told his story to this section in his own simple words on his return. The distance across was about 10 degrees, and the highest point was about one-third of the way across from the east coast. If the scientific results were necessarily somewhat meager, Dr. Nansen established a reputation for bravery and physical endurance, which he hopes to increase by an attempt to reach the North Pole. The *Fram* has already started from Hammerfest, and was telegraphed a few weeks ago from Waigatz Island. The intention is to enter the Kara Sea and to push northward and eastward, hoping that the warm currents caused by the great Siberian rivers will enable them to get well into the ice before winter begins. Once frozen into the pack ice, Nansen hopes to be carried by the currents somewhere near the North Pole, and, after drifting for two or three years, he hopes finally to emerge from his ice prison somewhere on the east coast of Greenland. Foolhardy as the expedition appears, it is nevertheless planned with great skill, and its chances of success are supposed to be based upon a sufficiently accurate knowledge of the ocean currents of the Polar Basin.

These currents, so far as they are known, are very interesting. The Mackenzie and the great Siberian rivers flow into the Polar Basin, and the current through Bering Strait is supposed to do the same; but both these sources of supply can only be regarded as of minor importance. Between Spitzbergen and Finmark, however, the Gulf Stream enters the Polar Basin 300 or 400 miles wide. To compensate for these inward currents, there are two outward currents, one on each side of Greenland, which, coming from the center of cold, do their best to intensify the rigors of that mountainous island.

Nansen hopes that the current which carried the *Jeannette* from Herald Island, north of Bering Strait, in a northwesterly direction for 500 or 600 miles, is the same current that flows down the east coast of

Greenland, and he bases his hopes upon three facts. First, that many articles from the wreck of the *Jeannette* were found on an ice-floe off the south coast of Greenland three years afterward; second, that a harpoon-thrower of a pattern unknown except in Alaska was picked up on the southwest coast of Greenland; and, third, that driftwood supposed to be of Siberian origin is stranded regularly in considerable quantity on the coasts of Greenland. The Norwegian at Hammerfest, about latitude 70°, is dependent for his firewood upon the Gulf Stream, which brings him an ample supply from the Gulf of Mexico, whilst the Eskimo on the Greenland coast, in the same latitude, trusts to a current from the opposite direction to bring him his necessary store of wood from the Siberian forests.

We can only hope that Nansen will find the currents as favorable to his needs, and that so much bravery may be supported by good luck.

THE RIVER SYSTEMS.

By no means the least important physical feature of the Polar Basin is its gigantic river systems.

The rivers which flow into the Arctic Ocean are some of them amongst the greatest in the world.

Some idea of the relative sizes of the drainage areas of a few of the best known rivers may be learned from the following table, in which the Thames, with a drainage area of 6,000 square miles, is the unit:

9 Thames		1 Elbe (54,000).
2 Elbes	=	1 Pechora (108,000).
2½ Pechoras	=	1 Danube (270,000).
2 Danubes	=	1 Mackenzie (540,000)
2 Mackenzies	=	1 Yenisei (1,080,000).
2 Yeniseis	=	1 Amazon (2,160,000).

Perhaps a more scientific classification of rivers would be to call those with a drainage area between 2,560 000 and 1,280 000 square miles rivers of the first magnitude, a category which contains the Amazon alone. There are ten rivers of the second magnitude, with drainage areas between 1,280,000 and 640,000 square miles (Ob, Congo, Mississippi, La Plata, Yenisei, Nile, Lena, Niger, Amur, Yangtse). There are twelve rivers of the third magnitude, with drainage areas between 640,000 and 320,000 square miles (Mackenzie, Volga, Murray, Zambesi, Saskatchewan, Ganges, St. Lawrence, Orange, Orinoco, Hoang Ho, Indus, and Bramaputra). There are more than a dozen rivers of the fourth magnitude, with drainage areas between 320,000, and 160,000 square miles, but none of them empties itself into the Arctic Ocean. They include the Danube, Euphrates, and several of the African and South American rivers. Of the numerous rivers which are of the fifth magnitude, with drainage areas between 160,000 and 80,000 square miles, the Pechora belongs to the Polar Basin. The number of rivers

of lesser magnitude is legion, and it is only necessary to quote one of each as an example.

Sixth magnitude (80,000 to 40,000), Rhine.
Seventh magnitude (40,000 to 20,000), Rhone.
Eighth magnitude (20,000 to 10,000), Garonne.
Ninth magnitude (10,000 to 5,000), Thames.

There is nothing that makes a greater impression upon the Arctic traveller than the enormous width of the rivers. The Pechora is only a river of the fifth magnitude, but it is more than 1 mile wide for several hundred miles of its course. The Yenisei is more than 3 miles wide for at least 1,000 miles, and 1 mile wide for nearly another thousand. Whymper describes the Yukon as varying from 1 mile to 4 miles in width for 300 or 400 miles of its length. The Mackenzie is described as averaging 1 mile in width for more than 1,000 miles, with occasional expansions for long distances to twice that size.

The drainage area does not measure the size of the Arctic rivers at all adequately. Though the rainfall of many of them is comparatively small, the size of the rivers is relatively very large, owing to the sudden melting of the winter's accumulation of snow, which causes an annual flood of great magnitude, like the rising of the Nile. Even on the Amur in eastern Siberia and on the Yukon in Alaska the annual flood is important enough, but on the rivers which flow north into the Polar Sea the damming up of the mouths by the accumulations of ice produces an annual deluge, frequently extending over thousands of square miles,—a catastrophe the effects of which have been much underrated and never adequately described.

If we assume that the unknown regions are principally sea, then the Polar Basin, including the area drained by all rivers flowing into the Arctic Sea, may be roughly estimated to contain about 14,000,000 square miles, of which half is land and half water. In the coldest part of the basin the land is either glacier or tundra, and in the warmer parts it is either forest or steppe.

GREENLAND GLACIERS.

Greenland, the home of the glacier and the mother of the icebergs of the Northern Atlantic, rises 9,000 or 10,000 feet above sea level, whilst the sea between that lofty plateau and Scandinavia is the deepest known in the Polar Basin, though it is separated from the rest of the Atlantic by a broad belt or submarine plateau connecting Greenland across Iceland and the Faroes with the British islands and Europe. Iceland, Spitzbergen, and Novaya-Zemlia, the latter a continuation of the Urals, are all mountainous and full of glaciers. The glaciers of southern Alaska are some of the largest in the world. The glaciers and the icebergs have a literature of their own, and we must pass them by to say a word or two about the tundra.

THE TUNDRA.

The Arctic Sea, which lies at the bottom of the Polar Basin, is fringed with a belt of bare country, sometimes steep and rocky, descending in more or less abrupt cliffs and piles of precipices to the sea, but more often sloping gently down in mud banks and sand hills representing the accumulated spoils of countless ages of annual floods, which tear up the banks of the rivers and deposit shoals of detritus at their mouths, compelling them to make deltas in their efforts to force a passage to the sea. In Norway this belt of bare country is called the fjeld, in Russia it is known as the tundra, and in America its technical name is the barren grounds. In the language of science, it is the country beyond the limit of forest growth.

In exposed situations, especially in the higher latitudes, the tundra does really merit its American name of barren ground, being little else than gravel beds interspersed with bare patches of peat or clay, and with scarcely a rush or a sedge to break the monotony. In Siberia, at least, this is very exceptional. By far the greater part of the tundra, both east and west of the Ural Mountains, is a gently undulating plain, full of lakes, rivers, swamps, and bogs. The lakes are diversified with patches of green water plants, amongst which ducks and swans float and dive; the little rivers flow between banks of rush and sedge; the swamps are masses of tall rushes and sedges of various species, where phalaropes and ruffs breed, and the bogs are brilliant with the white fluffy seeds of the cotton grass. The groundwork of all this variegated scenery is more beautiful and varied still,—lichens and moss of almost every conceivable color, from the cream colored reindeer moss to the scarlet-cupped trumpet moss, interspersed with a brilliant alpine flora, gentians, anemones, saxifrages, and hundreds of plants, each a picture in itself, the tall aconites, both the blue and yellow species, the beautiful cloudberry, with its gay white blossom and amber fruit, the fragrant *Ledum palustre*, and the delicate pink *Andromeda polifolia*. In the sheltered valleys and deep water courses a few stunted birches, and sometimes large patches of willow scrub, survive the long severe winter, and serve as cover for willow grouse or ptarmigan. The Lapland bunting and red-throated pipit are everywhere to be seen, and certain favored places are the breeding-grounds of plovers and sandpipers of many species. So far from meriting the name of barren ground, the tundra is for the most part a veritable paradise in summer. But it has one almost fatal drawback—it swarms with millions of mosquitoes.

ARCTIC FORESTS.

The tundra melts away insensibly into the forest, but isolated trees are rare, and in Siberia there is an absence of young wood on the confines of the tundra. The limit of forest growth appears to be retiring southward, if we may judge from the number of dead and dying stumps;

but this may be a temporary or local variation caused by exceptionally severe winters. The limit of forest growth does not coincide with the isotherms of mean annual temperature, nor with the mean temperature for January nearly so closely as it does with the mean temperature for July. It may be said to approximate very nearly to the July isotherm of 53° F. We may therefore assume that a 6-foot blanket of snow prevents the winter frosts from killing the trees so long as they can be revivified by a couple of months of summer heat above 50° F.

The limit of forest growth is thus directly determined by geographical causes. In Alaska and in the Mackenzie Basin it extends about 300 miles above the Arctic Circle, but in eastern Canada the depression of Hudson Bay acts as a vast ice-house, and the forest line falls 500 miles below the Arctic Circle, whilst on the east coast of Labrador the Arctic current from Baffins Bay sends it down nearly as far again. On the other side of the Atlantic the limit of forest growth begins on the Norwegian coast on the Arctic Circle, gradually rises until it reaches 200 miles farther north in Lapland, is depressed again by the ice-house of the White Sea, but has recovered its position in the valley of the Pechora, which is rather more than maintained until a second vast ice-house, the Sea of Okotsk, combined with Arctic currents, repeats the depression of Labrador in Chuski Land and Kamchatka.

There are no trees on Novaya-Zemlia. Two or three species of willow grow there, but they are dwarfs, seldom attaining a height of 3 inches. Novaya-Zemlia enjoys a comparatively mild winter, the mean temperature of January, thanks to the influence of the Gulf Stream, being 15° F. above zero in the south and only 5° F. below zero in the north. The absence of trees is due to the cold summers, the mean temperature of July not reaching higher than 45° F. in the south, whilst in the north it only reaches 38° F.

The Indians of Canada have discovered that when they want to find water in winter it is easiest reached under thick snow, the thinnest ice on the river or lake being found under the thickest blanket of snow. On the same principle the tree roots defy the severe winters protected by their snow shields; but they must have a certain temperature (above 50° F.) to hold their own in summer.

The influence of the snow blanket is very marked in determining the depths to which the frost penetrates beneath it. Thus we find that a Norwegian writer, alluding to latitude 62°, remarks "that the ground is frozen from 1 to 2½ feet in winter, but this depends upon how soon the snow falls. Higher up the mountains the ground is scarcely frozen at all, owing to the snow falling sooner, and in fact if the snow falls very early lower down it is scarcely frozen to any depth." Similar facts have been recorded from Canada in latitude 53°. "On this prairie land, when there is a good fall of snow when the winter sets in, the frost does not penetrate so deep as when there is no snow till late." Another writer a little farther south, in latitude 51°, says: "I am safe

in saying that the frost penetrates here to an average of 5 feet, except when we have had a great depth of snow in the beginning of winter, in which case it does not penetrate nearly so far."

THE STEPPE REGIONS.

It is not so easy to explain the boundary line between the forest and the steppe. There are two great steppe regions in the Polar Basin, one in Asia and the other in America. The great Barabinski Steppe in southwest Siberia stretches with but slight interruptions across southern Russia into Bulgaria. The great prairie region of Minnesota and Manitoba reaches the McKenzie Basin, and outlying plains are found almost up to the Great Slave Lake. The cause of the treeless condition of the steppes or prairies has given rise to much controversy. My own experience in Siberia convinced me that the forests were rocky and the steppes covered with a deep layer of loose earth, and I came to the conclusion that on the rocky ground the roots of the trees were able to establish themselves firmly so as to defy the strongest gales, which tore them up when they were planted in light soil. Other travellers have formed other opinions. Some suppose that the prairies were once covered with trees, which have been gradually destroyed by fires. Others suggest that the earth on the treeless plains contains too much salt or too little organic matter to be favorable to the growth of trees. No one, so far as I know, has suggested a climatic explanation of the circumstance. Want of drainage may produce a swamp and the deficiency of rainfall may cause a desert, both conditions being fatal to forest growth, but no one can mistake either of these treeless districts for a steppe or prairie.

ARCTIC ANTHROPOLOGY.

The anthropology of the Polar Basin presents many points of interest. On the American coasts of the Arctic Ocean the Eskimo lives a very similar life to the Lapp in Norway and the Samoyede in the tundras of Siberia. These races of men resemble each other very much in their personal appearance, and still more so in their habits. Their straight black hair, with little or no beard, their dark and obliquely set eyes, their high cheek bones and flat noses, and their small hands and feet. testify to their Mongoloid origin. They are all indebted to the reindeer for some of their winter dress and for much of their food, and they all have dogs; but the Eskimo travels only with dogs, and the Lapp only with reindeer, whilst the Samoyede uses both dog sledges and reindeer sledges. They all lead a nomadic life, trapping fur-bearing animals in winter and fishing in summer; they resemble each other in many other customs and beliefs, but they are nevertheless supposed to have emigrated to the Arctic regions from independent sources, and many characters in which they resemble each other are supposed to have been independently acquired.

The various races which inhabit the Polar Basin below the limit of forest growth are too numerous to be considered in detail.

ARCTIC ZOOLOGY.

Most zoologists divide the Polar Basin into two zoological regions, or, to be strictly accurate, they include the Old World half of the Polar Basin in what they call the Palæarctic region, and the New World half in the Nearctic region: but recent investigations have shown that these divisions are unnatural and can not be maintained. Some writers unite the two regions together under the name of the Holarctic region, whilst others recognize a circumpolar Arctic region above the limit of forest growth, and unite in a second region the temperate portions of the Northern Hemisphere. In the opinion of the last-mentioned writers the circumpolar Arctic region differs more from the temperate regions of the Northern Hemisphere than the American portion of the latter does from the Eurasian portion.

The fact is that life areas, or zoo-geographical regions, are more or less fanciful generalizations. The geographical distribution of animals, and probably also that of plants, is almost entirely dependent upon two factors, *climate* and *isolation*, the one playing quite as important a part as the other. The climate varies in respect of rain-fall and temperature, and species are isolated from each other by seas and mountain ranges. The geographical facts which govern the zoological provinces consequently range themselves under these four heads. It is at once obvious that the influences which determine the geographical distribution of fishes must be quite different from those which determine the distribution of mammals, since the geographical features which isolate the species in the one case are totally different from those which form impassable barriers in the other. It is equally obvious that the climate conditions which influence the geographical range of mammals must include the winter cold as well as the summer heat, whilst those which determine the geographical distribution of birds (most of which are migratory in the Arctic regions) are entirely independent of any amount of cold which may descend upon their breeding grounds during the months which they spend in their tropic or sub-tropic winter quarters.

Hence all attempts to divide the Polar Basin into zoological regions or provinces are futile. Nearly every group of animals has zoological regions of its own, determined by geographical features peculiar to itself, and any generalizations from these different regions can be little more than a curiosity of science. The mean temperature or distribution of heat can be easily ascertained. It is easy to generalize so as to arrive at an average between the summer heat and the winter cold, because they can be both expressed in the same terms. When however we seek to generalize upon the distribution of animal or vegetable life, how is it possible to arrive at a mean geographical distribution of

animals? How many genera of mollusks are equal to a genus of mammals, or how many butterflies are equal to a bird?

If there be any region of the world with any claim to be a life area, it is that part of the Polar Basin which lies between the July isotherm of 50° or 53° F. and the northern limit of organic life. The former corresponds very nearly with the northern limit of forest growth, and they comprise between them the barren grounds of America and the tundras of Arctic Europe and Siberia.

The fauna and flora of this circumpolar belt is practically homogeneous; many species of both plants and animals range throughout its whole extent. It constitutes a circumpolar Arctic region, and can not consistently be separated at Bering Strait into two parts of sufficient importance to rank even as sub-regions.

Animals recognize facts and are governed by them in the extension of their ranges; they care little or nothing about generalizations. The mean temperature of a province is a matter of indifference to some plants and to most animals. The facts which govern their distribution are various, and vary according to the needs of the plant or animal concerned. To a migratory bird the mean annual temperature is a matter of supreme indifference. To a resident bird the question is equally beside the mark. The facts which govern the geographical distribution of birds are the extremes of temperature, not the means. Arctic birds are nearly all migratory. Their distribution during the breeding season depends primarily on the temperature of July, which must range between 53° and 35° F. It is very important however to remember that it is actual temperature that governs them, not isotherms corrected to sea level. If an Arctic bird can find a correct isotherm below the Arctic Circle by ascending to an elevation of 5,000 or 6,000 feet above the level of the sea, it avails itself of the opportunity. Thus the region of the Dovrefeld above the limit of forest growth is the breeding place of many absolutely Arctic birds; but this is not nearly so much the case on the Alps, because the cold nights vary too much from the hot days to come within the range of the birds' breeding grounds. Here, again, the mean daily temperature is of no importance. It is the extreme of cold which is the most potent factor in this case, and no extreme of heat can counter-balance its effect.

POLAR ISOTHERMALS.

In estimating the influence of elevation upon temperature it has been ascertained that it is necessary to deduct about 3° F. for every thousand feet. The isothermal lines are very eccentric in the Polar Basin. The mean temperature of summer is quite independent of that of winter. The isothermal lines of July are regulated by geographical causes which do not affect those of December or operate in a contrary direction. The Gulf Stream raises the mean temperature of Iceland during winter to the highest point which it reaches in the Polar Basin,

viz, 30° to 35° F., whilst in summer it prevents it from rising above 45° and 50° F., a range of only 15°. In the valley of the Lena, in the same latitude, the mean temperature of January is 55° to 50° F. below zero, whilst that of July is 60° to 65° F. above zero, a range 115°.

The close proximity of the Pacific Ocean has a much less effect on the mean temperature at Bering Strait, which is in the same latitude as the north of Iceland. The mean temperature for January is zero, whilst that for July is 40° F. The mean temperature for January in the same latitude in the valley of the Mackenzie is 25° below zero, whilst that for July is 55° F. In this case the contrast of the ranges is 40 and 80, which compared with 15 and 115 is small, but the geographical conditions are not the same. Bering Sea is so protected by the Aleutian chain of islands that very little of the warm current from Japan reaches the straits. It is deflected southward, so the Aleutian Islands form a better basis for comparison. Their mean temperature for January is 35° F., whilst that for July is 50° F., precisely the same difference as that to be found in Iceland.

The influence of geographical causes upon climate being at present so great, it is easy to imagine that changes in the distribution of land and water may have had an equally important influence upon the climate of the Polar Basin during the recent cold age, which geologists call the Pleistocene period. It is impossible for the traveler to overlook the evidences of this so-called Glacial period in the Polar Basin; and whether we seek an explanation of the geographical phenomena from the astronomer or the geologist, or both, it is impossible to ignore the geographical interest of the subject.

ARCTIC GEOLOGY.

No sciences can be more intimately connected than geography and geology. A knowledge of geography is absolutely essental to the geologist. To discriminate between one kind of rock and another is a comparatively small part of the work of the geologist. To ascertain the geographical distribution of the various rocks is a study of profound interest. If the geologist owes much to the geographer, the latter is also largely indebted to the labors of the former. The geology of a mountain range or an extended plain is as important to the physical geographer as the knowledge of anatomy is to the figure painter.

The geology of the Polar Basin is not very accurately known, and the subject is one too vast to be more than mentioned on an occasion like the present; but the evidences of a comparatively recent ice age in eastern America and western Europe are too important to be passed by without a word.

In the sub-arctic regions of the world there is much evidence to show that the climate has in comparatively recent times been Arctic. The present glaciers of Central Europe were once much greater than

they are now, and even in the British Islands glaciers existed during what has been called the ice age, and the evidence of their existence in the form of rocks, upon which they have left their scratches, and heaps of stones which they have deposited in their retreat, are so obvious that he who runs may read. Similar evidence of an ice age is found in North America, and to a limited extent in the Himalayas, but in the alluvial plains of Siberia and North Alaska, as might be expected, no trace of an ice age can be found.

Croll's hypothesis that an ice age is produced when the eccentricity of the earth's orbit is unusually great, has been generally accepted as the most plausible explanation of the facts. It is assumed that during the months of summer perihelion evaporation is extreme, and that during the months of winter aphelion the snow-fall is considerably increased. The effect of the last period of high eccentricity is supposed to have been much increased by geographical changes. The elevation of the shallow sea which connects Iceland with Greenland on the one hand, and the south of Norway and the British Islands on the other, would greatly increase the accumulation of snow and ice in those parts of the Polar Basin where evidence of a recent ice age is now to be found; whilst the depression of the lowlands on either side of the Ural Mountains so as to admit the waters of the Mediterranean through the Black and Caspian Seas, might prevent any glaciation in those parts of the Polar Basin where no evidence of such a condition is now discoverable. But this is a question that must be left to the geologist to decide.

The extreme views of the early advocates of the theory of an ice age have been to a large extent abandoned. No one now believes in the former existence of a Polar ice cap, and possibly, when the irresistible force of ice-dammed rivers has been fully realized, the estimated area of glaciation may be considerably reduced. The so-called great ice age may have been a great snow age, with local centers of glaciation on the higher grounds.

The zoological evidence as to the nature, extent, and duration of the ice age has never been carefully collected. The attention of zoologists has unfortunately been too exclusively devoted to the almost hopeless task of theorizing upon the causes of evolution, instead of patiently cataloguing its effects.

There is a mass of evidence bearing directly upon the recent changes in the climate of the Polar Basin to be found in the study of the present geographical distribution of birds. The absence of certain common British forest birds (some of them of circumpolar range sub-generically, if not specifically) from Ireland and the north of Scotland is strong confirmation of the theory that the latter countries were not very long ago outside the limit of forest growth.

The presence of species belonging to Arctic and sub-Arctic general on many of the South Pacific islands is strong evidence that they were

compelled to emigrate in search of food by some great catastrophe, such as an abnormally heavy snow-fall, and the fact that no island contains more than one species is strong evidence that this great catastrophe has only occurred once in recent times. The occurrence of a well recognized line of migration from Greenland across Iceland, the Faroes, and the British Islands to Europe is strongly suggestive of a recent elevation of the land where the more shallow sea now extends in this locality. The extraordinary similarity of the fauna and flora of the Arctic regions of the Old and the New Worlds can only be found elsewhere in continuous areas, and had it not been for the unfortunate division of the Arctic region into two halves, Palæarctic and Nearctic, would have attracted much more attention than it has hitherto received.

ARCTIC CLIMATE.

The rain-fall of the Polar Basin is small compared to that with which we are familiar, but its visible effects are enormous. In Arctic Europe and Siberia it is supposed to average about 13 inches per annum; in Arctic America not more than 9 inches. The secret of its power is that about a third of the rain-fall descends in the form of snow, which melts with great suddenness.

The stealthy approach of winter on the confines of the Polar Basin is in strong contrast to the catastrophe which accompanies the sudden onrush of summer. One by one the flowers fade, and go to seed if they have been fortunate enough to attract by their brilliancy a bee or other suitable pollen-bearing visitor. The birds gradually collect into flocks and prepare to wing their way to southern climes. Strange to say, it is the young birds of each species that set the example. They are not many weeks old. They have no personal experience of migration, but nature has endowed them with an inherited impulse to leave the land of their birth before their parents. Probably they inherit the impulse to migrate without inheriting any knowledge of where their winter quarters are to be found, and by what route they are to be sought. They are sometimes, if not always, accompanied by one or two adults; it may be barren birds, or birds whose eggs or young have been destroyed, or who may therefore get over their autumn molt earlier than usual, or molt slowly as they travel southward. Of most species the adult males are the next to leave, to be followed perhaps a week later by the adult females. One by one the various migratory species disappear, until only the few resident birds are left, and the Arctic forest and tundra resume the silence so conspicuous in winter. As the nights get longer the frosts bring down the leaves from the birch and the larch trees. Summer gently falls asleep, and winter as gently steals a march upon her, with no wind and no snow, until the frost silently lays its iron grip upon the river, which, after a few impotent struggles, yields to its fate. The first, and mayhap the second ice is broken up, and when the *starrester* of the

village sallies forth to peg out with rows of birch trees the winter road down the river to the next village, for which he is responsible, he has frequently to deviate widely from the direct course in his efforts to choose the smoothest ice, and find a channel between the hummocks that continually block the way.

The date upon which winter resumes his sway varies greatly in different localities, and probably the margin between an early and a late season is considerable. In 1876, Capt. Wiggins was frozen up in winter quarters on the Yenisei, in latitude 66½°, on October 17. In 1878 Capt. Palander was frozen up on the coast 120 miles west of Bering Strait, in latitude 67¾°, on September 28.

The sudden arrival of summer on the Arctic Circle appears to occur nearly at the same date in all the great river basins, but the number of recorded observations is so small that the slight variation may possibly be seasonal and not local. The ice on the Mackenzie River is stated by one authority to have broken up on May 13, in latitude 62°, and by another on May 9 in latitude 67°. If the Mackenzie breaks up as fast as the Yenisei—that is to say at the rate of a degree a day, an assumption which is supported by what little evidence can be found—then the difference between these two seasons would be nine days. My own experience has been that the ice of the Pechora breaks up ten days before that of the Yenisei, but as I have only witnessed one such event in each valley, too much importance must not be attached to the dates.

According to the Challenger tables of isothermal lines, the mean temperatures of January and July on the Arctic Circle in the valleys of the Mackenzie and the Yenisei scarcely differ, the summer temperature in each case being about 55° F., and that of winter —25° F., a difference of 80° F.

On the American side of the Polar Basin summer comes almost as suddenly as it does on the Asiatic side, but the change appears to be less of the nature of a catastrophe. The geographical causes which produce this result are the smaller area of the river basins and the less amount of rain-fall. There is only one large river which empties itself into the Arctic Ocean on the American side, the Mackenzie, with which may be associated the Saskatchewan, which discharges into Hudson Bay far away to the south. The basin of the Mackenzie is estimated at 590,000 square miles, whilst that of the Yenisei is supposed to be exactly twice that area. The comparative dimensions of the two summer floods are still more diminished by the difference in the quantity of snow.

The snow in the Mackenzie basin is said to be from 2 to 3 feet deep, whilst that in the Yenisei basin is from 5 to 6 feet deep, so that the spring flood in the latter river must be about five times as large as that of the former.

Another feature in which the basin of the Mackenzie differs from those of the rivers in the Arctic regions of the Old World is the number of rapids and lakes contained in it. The ice in the large lakes attains

a thickness at least twice as great as that of the rapid stream, and consequently breaks up much later. In the Great Slave Lake the ice attains a depth of 6 to 7 feet, and even in the Athabaska Lake, in latitude 58°, it reaches 4 feet. The rapids between these two lakes extend for 15 miles. The ice on the river breaks up a month before that on the lakes, so that the drainage area of the first summer flood is much restricted.

The arrival of summer in the Arctic regions happens so late that the inexperienced traveller may be excused for sometimes doubting whether it really is going to come at all. When continuous night has become continuous day without any perceptible approach to spring, an Alpine traveller naturally asks whether he has not reached the limit of perpetual snow. It is true that here and there a few bare patches are to be found on the steepest slopes where most of the snow has been blown away by the wind, especially if these slopes face the south, where even an Arctic sun has more potency than it has elsewhere. It is also true that small flocks of little birds—at first snow buntings and mealy redpoles, and later shore larks and Lapland buntings—may be observed to flit from one of these bare places to another looking for seeds or some other kind of food, but after all, evidently finding most of it in the droppings of the peasants' horses on the hard snow-covered roads. The appearance of these little birds does not however give the same confidence in the eventual coming of summer to the Arctic naturalist as the arrival of the swallow or the cuckoo does to his brethren in the sub-arctic and subtropic climates. The four little birds just mentioned are only gipsy migrants that are perpetually flitting to and fro on the confines of the frost, continually being driven south by snow-storms, but ever ready to take advantage of the slightest thaw to press northward again to their favorite Arctic home. They are all circumpolar in their distributions, are as common in Siberia as in Lapland, and range across Canada to Alaska, as well as to Greenland. In sub-arctic climates we see them only in winter, so that their appearance does not in the least degree suggest the arrival of summer to the traveller from the south.

The gradual rise in the level of the river inspires no more confidence in the final melting away of the snow and the disruption of the ice which supports it. In Siberia the rivers are so enormous that a rise of 5 or 6 feet is scarcely perceptible. The Yenisei is 3 miles wide at the Arctic Circle, and as fast as it rises the open water at the margin freezes up again and is soon covered with the drifting snow. During the summer which I spent in the valley of the Yenisei we had 6 feet of snow on the ground until the 1st of June. To all intents and purposes it was mid-winter, illuminated for the nonce with what amounted to continuous daylight. The light was a little duller at midnight, but not so much so as during the occasional snowstorms that swept through the forest and drifted up the broad river bed. During the month of May there were a few signs of the possibility of some mitigation of the rigors of winter. Now and then there was a little rain, but it was

always followed by frost. If it thawed one day, it froze the next, and little or no impression was made on the snow. The most tangible sign of coming summer was an increase in the number of birds, but they were nearly all forest birds, which could enjoy the sunshine in the pines and birches, and which were by no means dependent on the melting away of the snow for their supply of food. Between May 16 and 30 we had more definite evidence of our being within bird flight of bare grass or open water. Migratory flocks of wild geese passed over our winter quarters, but if they were flying north one day they were flying south the next, proving beyond all doubt that their migration was premature. The geese evidently agreed with us that it ought to be summer, but it was as clear to the geese as to us that it really was winter.

We afterward learned that during the last ten days of May a tremendous battle had been raging 600 miles, as the crow flies, to the southward of our position on the Arctic Circle. Summer in league with the sun had been fighting winter and the north wind all along the line, and had been as hopelessly beaten everywhere as we were witnesses that it had been in our part of the river. At length, when the final victory of summer looked the most hopeless, a change was made in the command of the forces. Summer entered into an alliance with the south wind. The sun retired in dudgeon to his tent behind the clouds; mists obscured the landscape; a soft south wind played gently on the snow, which melted under its all-powerful influence like butter upon hot toast; the tide of battle was suddenly turned; the armies of winter soon vanished into thin water and beat a hasty retreat toward the pole. The effect on the great river was magical. Its thick armor of ice cracked with a loud noise like the rattling of thunder; every twenty-four hours it was lifted up a fathom above its former level, broken up, first into ice floes and then into pack ice, and marched downstream at least 100 miles. Even at this great speed it was more than a fortnight before the last straggling ice blocks passed our post of observation on the Arctic Circle; but during that time the river had risen 70 feet above its winter level, although it was 3 miles wide and we were in the middle of a blazing hot summer, picking flowers of a hundred different kinds and feasting upon wild ducks' eggs of various species. Birds abounded to an incredible extent. Between May 29 and June 18 I identified sixty-four species which I had not seen before the break-up of the ice. Some of them stopped to breed and already had eggs, but many of them followed the retreating ice to the tundra, and we saw them no more until, many weeks afterward, we had sailed down the river beyond the limit of forest growth.

The victory of the south wind was absolute, but not entirely uninterrupted. Occasionally the winter made a desperate stand against the sudden onrush of summer. The north wind rallied its beaten forces for days together, the clouds and the rain were driven back, and

the half-melted snow frozen on the surface. But it was too late; there were many large patches of dark ground which rapidly absorbed the sun's heat, the snow melted under the frozen crust, and its final collapse was as rapid as it was complete.

In the basin of the Yenisei the average thickness of the snow at the end of winter is about 5 feet. The sudden transformation of this immense continent of snow, which lies as gently on the earth as an eider-down quilt upon a bed, into an ocean of water rushing madly down to the sea, tearing everything up that comes into its way, is a gigantic display of power, compared with which an earthquake sinks into insignificance. It is difficult to imagine the chaos of water which must have deluged the country before the river beds were worn wide enough and deep enough to carry the water away as quickly as is the case now. If we take the Lower Yenisei as an example, it may be possible to form some conception of the work which has already been done. At Yeniseisk the channel is about a mile wide; 800 miles lower down (measuring the windings of the river), at the village of Kureika, it is about 3 miles wide; and following the mighty stream for about another 800 miles down to the Brekoffsky Islands, it is nearly 6 miles wide. The depth of the channel varies from 50 to 100 feet above the winter level of the ice. This ice is about 3 feet thick, covered with 6 feet of snow, which becomes flooded shortly before the break-up and converted into about 3 feet of ice, white as marble, which lies above the winter blue ice. When the final crash comes, this field of thick ice is shattered like glass. The irresistible force of the flood behind tears it up at an average rate of 4 miles an hour, or about 100 miles a day, and drives it down to the sea in the form of ice floes and pack ice. Occasionally a narrow part of the channel or a sharp bend of the river causes a temporary check; but the pressure from behind is irresistible, the pack ice is piled into heaps, and the ice floes are doubled up into little mountains, which rapidly freeze together into icebergs, which float off the banks as the water rises. Meanwhile, other ice floes come up behind; some are driven into the forests, where the largest trees are mown down by them like grass, whilst others press on until the barrier gives way and the waters, suddenly let loose, rush along at double speed, carrying the icebergs with them with irresistible force, the pent-up dam which has accumulated in the rear often covering hundreds of square miles. In very little more than a week the ice on the 800 miles, from Yeniseisk to the Kureika, is completely broken up, and in little more than another week the second 800 miles, from the Kureika to the Brekoffsky Islands, is in the same condition.

During the glacial epoch the annual fight between winter and the sun nearly always ended in the victory of the former. Even now the fight is a very desperate one within the Polar Circle and is subject to much geographical variation. The sun alone has little or no chance. The armies of winter are clad in white armor, absolutely proof against

the sun's darts, which glance harmlessly on 6 feet of snow. In these high latitudes the angle of incidence is very small, even at midday in midsummer. The sun's rays are reflected back into the dry air with as little effect as a shell which strikes obliquely against an armor plate. But the sun does not fight his battle alone. He has allies which, like the arrival of the Prussians on the field of Waterloo, finally determine the issue of the battle in his favor. The tide of victory turns earliest in Norway, although the Scandinavian Fjeld forms a magnificent fortress, in which the forces of winter intrench themselves in vain. This fortress looks as impregnable as that on the opposite coast, and would doubtless prove so were it not for the fact that in this part of the Polar Basin the sun has a most potent ally in the Gulf Stream, which soon routs the armies of winter and compels the fortress to capitulate.

The suddenness of the arrival of summer in Siberia is probably largely due to the geographical features of the country. In consequence of the vastness of the area which is drained by the great rivers, and the immense volume of water which they have to carry to the sea, the break up of the ice in their lower valleys precedes, instead of being caused by, the melting of the snow toward the limit of forest growth. The ice on the effluents either breaks up after that on the main river, or is broken up by irresistible currents from it which flow up stream,—an anomaly for which the pioneer voyager is seldom prepared; and when the captain has escaped the danger of battling against an attack of pack ice and ice floes from a quarter whence it was entirely unexpected, he may be suddenly called upon to face a second army of more formidable ice floes and pack ice from the great river itself, and if his ship survive the second attack a third danger awaits him in the alternate rise and fall of the tributary as each successive barrier where the ice gets jammed in its march down the main stream below the junction of the river accumulates until the pressure from behind becomes irresistible, when it suddenly gives way. This alternate advance and retreat of the beaten armies of winter continued for about ten days during the battle between summer and winter of which I was a witness in the valley of the Yenisei. On one occasion I calculated that at least 50,000 acres of pack ice and ice floes had been marched up the Kureika. The marvel is what became of it. To all appearance half of it never came back. Some of it no doubt melted away during the ten days' marches and countermarches; some drifted away from the river on the flooded places, which are often many square miles in extent; some got lost in the adjoining forests, and was doubtless stranded among the trees when the flood subsided; and some were piled up in layers one upon the top of the other, which more or less imperfectly froze together and formed icebergs of various shapes and sizes. Some of the icebergs which we saw going down the main stream were of great size, and as nearly as we could estimate stood from 20 to 30 feet above the surface of the water. These immense blocks appeared to be moving at the rate of from 10 to 20 miles an hour. The grinding together of the

sharp edges of the innumerable masses of ice as they were driven down stream by the irresistible pressure from behind produced a shrill rustling sound that could be heard a mile from the river.

The alternate marching of this immense quantity of ice up and down the Kureika was a most curious phenomenon. To see a strong current up stream for many hours is so contrary to all previous experience of the behavior of rivers that one can not help feeling continuous astonishment at the novel sight. The monotony which might otherwise have intervened in a ten days' march past of ice was continually broken by complete changes in the scene. Sometimes the current was up stream, sometimes it was down, and occasionally there was no current at all. Frequently the pack ice and ice floes were so closely jammed together that there was no apparent difficulty in scrambling across them, and occasionally the river was free from ice for a short time. At other times the river was thinly sprinkled over with ice blocks and little icebergs, which occasionally "calved" as they travelled on, with much commotion and splashing. The phenomenon technically called "calving" is curious, and sometimes quite startling. It takes place when a number of scattered ice blocks are quietly floating down stream. All at once a loud splash is heard as a huge lump of ice rises out of the water, evidently from a considerable depth, like a young whale coming up to breathe, noisily beats back the waves that the sudden upheavel has caused, and rocks to and fro for some time before it finally settles down to its floating level. There can be little doubt that what looks like a comparatively small ice block floating innocently along is really the top of a formidable iceberg, the greater part of which is a submerged mass of layers of ice piled one on the top of the other, and in many places very imperfectly frozen together. By some accident, perhaps by grounding on a hidden sandbank, perhaps by the water getting between the layers and thawing the few places where they are frozen together, the bottom layer becomes detached, escapes to the surface, and loudly asserts its commencement of an independent existence with the commotion in the water which generally proclaims the fact that an iceberg has calved.

Finally comes the last march-past of the beaten forces of winter, the ragtag and bobtail of the great Arctic army that comes straggling down the river when the campaign is all over—worn and weather-beaten little icebergs, dirty ice floes that look like floating sandbanks, and straggling pack ice in the last stages of consumption that looks strangely out of place under a burning sun between banks gay with the gayest flowers, amidst the buzz of mosquitoes, the music of song birds, and the harsh cry of gulls, divers, ducks, and sandpipers of various species.

I have been thus diffuse in describing these scenes, in the first place, because they are very grand; in the second place, because they have so important a bearing upon climate, one of the great factors which determine the geographical distribution of animals and plants; and in the third place, because they have never been sufficiently emphasized.

ARCTIC REGIONS.

(Reproduced from Scottish Geographical Magazine, 1892.)

THE PRESENT STANDPOINT OF GEOGRAPHY.*

By Clements R. Markham, F. R. S.

The work of geographical discovery, during living memory, has proceeded with such rapidity that many of us have been half inclined to think that there is little left to be done. Brilliantly successful expeditions have traversed the unknown parts of the great continents, blank es on our maps have been filled up year after year, entrancing narratives of perilous adventure have held us in rapt attention during each succeeding session, until we are tempted to believe that the glorious tale is nearly told. But this is very far indeed from being the case. There are still wide tracts, in all the great divisions of the earth, which are unknown to us, and which will furnish work to explorers for many years to come, while the examination of ocean depths is an important task which has but lately been commenced. Moreover, there are regions of vast extent which are only very partially known to us, the more detailed examination of which will enable explorers to collect geographical information of the highest value and of the greatest interest. It is from the methodical study of limited areas that science derives the most satisfactory results. When such investigations are commenced it is found how meager and inaccurate previous knowledge derived from the cursory information, picked up during some rapid march, had been. A detailed scientific monograph on a little known region of comparatively small extent supplies work of absorbing interest to the explorer, while he has the satisfaction of knowing that his labors will be of lasting value and utility. There is sufficient work of this less ambitious, but not less serviceable kind to occupy a whole army of field geographers for many decades. Exact delineation, by trigonometrical measurement, is our crowning work. It is barely commenced. With the exception of countries in Europe, British India, the coast of the United States, and a small part of its interior, the whole world is still unmapped. Supposing that the surface of the earth does not undergo changes, our work will be completed centuries hence, when all the regions of the earth have been discovered, have been explored in detail,

*Opening address of the president, delivered at the meeting of the Royal Geographical Society, November 13, 1893. (*The Geographical Journal*, London, vol. II, pp. 481–504.)

and have been scientifically mapped. As the earth's surface is in constant process of change, our work will never be completed, and we must as a race of men labor at it without ceasing. We of this generation have received the torch of geographical knowledge from our fathers. It is for us to diffuse its light over a wider and wider circle while we live, and to hand it on, still burning brightly, to our descendants.

All of us, all the Fellows of this great Society, ought to work in our several lines and capacities, for all can help in the diffusion of the light of knowledge, some in one way, some in another. I have thought, therefore, that we might usefully set apart the opening night of our present session for taking a survey; it must necessarily be a rough and incomplete survey, but still a general survey of some of the work that is before us; of the regions that are still unknown and await discovery, of the tracts that seem most to need more detailed exploration, and of the principal geographical problems that remain to be solved. We may also glance at the ways in which our society has furnished in the past, and may still more in the future furnish aid toward furthering and helping in the great work that is always before us.

The Polar areas contain by far the most extensive unknown tracts on the globe. Explorers and geographers have been occupied with the Arctic regions for the last three centuries, and more especially during the last century. Their labors have added a very bright page to the story of British maritime achievement. The expeditions have brought back abundant valuable results in all branches of science, and by opening the way to lucrative fisheries have increased the wealth of the nation. But their great use has been that to which Lord Beaconsfield referred in 1874, "the importance of encouraging that spirit of enterprise which has ever distinguished the English people." At present it is our watch below as regards the Arctic regions. We have taken a back seat, from which we look on while others do the work. Mr. Peary, after a very perilous and adventurous reconnaissance last year, is now preparing, amidst all the hardships of an Arctic winter, for a supreme effort to solve one of the great remaining geographical problems, the insularity of Greenland. Our gallant friend Nansen is engaged upon a still more heroic enterprise. I believe that the argument on which his proceedings are based is sound. I know that if thorough knowledge, mature reflection, courage of the highest order, indomitable perseverance, and the faculty for command can secure success Nansen is the man to achieve it. But the natural obstacles are very great, and it may well be beyond human power to overcome them. We can only give these gallant men our warmest sympathy, and resolve that our welcome on their return shall be hearty and cordial.

But even when the great geographical problems with which Nansen and Peary are now grappling have been fully solved there will still be a vast unknown area within the Arctic Circle and much important work to be done. For several reasons I believe that there is land between Prince

Patrick Island and Siberia which ought to be discovered. The extent of the ancient ice ought to be ascertained by an expedition up Jones Sound. Franz Josef Land, particularly the coasts and islands on its northern face, offer materials of peculiar interest to the explorer. Mr. Jackson, who left last summer to explore the Yalmal Peninsula, has proposed to lead an expedition in this direction. The difficulties will be formidable and ought not to be disguised, but the value of the scientific results to be attained are well worth the unavoidable risk. Another direction for research is the area immediately to the north of Cape Chelyuskin, in Siberia, where Lieut. Hovgaard, on plausible grounds, believes that there is extensive land. It will occupy at least five successive Arctic expeditions, all entirely successful, to complete our knowledge of the North Polar area, and this society ought never to rest satisfied until the work is thoroughly done. For it must be borne in mind that this work will not only unfold to us the varied phenomena of the unknown regions. The earth's surface is a connected whole and its phenomena are inter-dependent. For example, the climate of Europe, as was pointed out in 1873, in no small degree depends on the atmospheric conditions of the Polar area. For the satisfactory appreciation of these phenomena a precise acquaintance with the distribution of land and water north of the Arctic Circle is quite necessary, and of that our knowledge is still very unlimited.

If a vast extent of the North Polar area is still unknown, and if, as is undoubtedly the case, its complete examination is a scientific desideratum, how much more is this the case within the South Polar area? The Antarctic regions, with millions of unknown square miles full of geographical work, and teeming with the most interesting scientific problems, have been totally neglected by us for half a century. It is not necessary that I should say more, because at our next meeting Dr. John Murray will address us fully on the important results to be derived from Antarctic discovery, and stir up our enthusiasm as geographers and our patriotism as Britons so that we may all combine in a hearty effort to procure the renewal of Antarctic research. Certainly fifty years is a long time for us to have totally neglected so vast and so important a field for geographical discovery. We may now look forward to a most interesting Antarctic meeting on November 27, and, meanwhile, we will continue our survey of the other parts of the world, which either need further exploration or are entirely unknown.

There is plenty of interesting work even in our quarter of the globe, although there are now no discoveries to be made. Even in our own islands some of the lakes are unsurveyed and were not systematically sounded until our accomplished librarian began the useful work in Cumberland this year. The topography of the Alps may be considered to be fairly complete, but there are still physical inquiries of great interest which commend themselves to scientific Alpine travelers, such as the extent and action of ice, the oscillations of glaciers, the origin of the Föhn

wind, and the effects of the destruction of forests. The historical geography of the Alps is also in process of elucidation, and in this department our associate, the Rev. W. B. Coolidge, of Magdalen College, Oxford, is one of the most industrious workers, but much remains to be done. It will be remembered too that our secretary, Mr. Douglas Freshfield, has written a paper on the long-disputed passage of the Alps by Hannibal, and, although his solution of the question has not been universally accepted, it is adopted in the latest edition of Arnold's "Rome." Beyond the Alps there is need of a fuller description of the Cantabrian Highlands along the north of Spain, but it is the Balkan Peninsula which offers the best new ground in Europe for mountain travelers. This year our Oxford travelling scholar, Mr. Cozens-Hardy, has been investigating one of the least-explored and worst-mapped regions in Europe, that on the frontiers of Montenegro. The value of his work is best shown by the fact that the intelligence department has undertaken the production of a map based on his observations. On the border land of Europe and Asia the Caucasus has been revealed to us, and we have been made familiar with the splendor of its forests and frozen crests within the last quarter of a century, thanks to our gold medallist, Dr. Radde, and other Alpine climbers. In this region Signor W. Sella, our honorary associate, M. de Déchy, and Mr. H. Woolley have conspicuously proved what photography can do to present a living picture of the physical features and of the inhabitants of a hitherto little known country. Recently the Russian Government has undertaken a survey of the Caucasus, and the results, as far as they are available, reflect the highest credit on the officers employed; but the range is of great extent, and here there is plenty of room for mountain travelers to break new ground.

The regions not yet traversed by explorers on the continent of Africa have shrunk very considerably since I became a fellow of this society. Barth and Vogel were then at work in the direction of Timbuctoo and Lake Chad, Dr. Baikie was on the Niger, Dr. Livingstone was making his way to the coast at Loando, and Mr. Galton's companion, Anderssen, had reached Lake Ngami; Burton had just proposed his expedition to Harar. Tanganyika, Victoria Nyanza, and Nyasa, the falls of the Zambesi, the heights of Kilimanjaro and Kenia had not been heard of. In those days almost every expedition that was sent into Africa revealed to us some geographical feature of commanding importance corroborating or refuting the theories and speculations of students.

At present there are only three regions, in Africa, of considerable area which offer opportunities for discovery on a large scale, namely, the Sahara, the region adjoining it to the south, and extending across Wadai to the watersheds of the Congo and Nile, and the region to the east of the Upper Nile, stretching south of Abyssinia, through the lands of the Gallas and Somalis, to the eastern seaboard of the continent.

In the Sahara there are more especially two districts which would reward an enterprising explorer. One has for its center the highlands of Tibesti, for our knowledge of which we are solely dependent on the reports of Nachtigal and Gerhard Rohlfs. The other is the highland of Ahaggar. Col. Flatters lost his life in an attempt to explore it in 1881, yet the difficulties can not be insurmountable. Great interest attaches to a thorough examination of the Atlas Mountains, but they are still rendered inaccessible in some parts by fanatical tribes.

The second large unknown African region includes Wadai and the districts lying between the scene of Junker's exploration in the east and the route recently taken by M. Maistre, in his journey from the Ubangi to the Shari. Wadai has only been visited by three Europeans. Dr. Vogel was murdered at Wara in 1856, and his diaries have never been recovered. Nachtigal crossed the country from west to east in 1873. Lieut. Masari did so in the opposite direction in 1880. A European traveller would doubtless meet with considerable difficulties in an exploration of Wadai proper, but the outlying districts of this region certainly deserve attention, and they are now much more easily accessible from the Ubagm-Welle, or the upper Benue, than they were some years ago.

Far more interesting, however, is the vast region, the greater part of which is unexplored, which stretches from the Upper Nile to the Indian Ocean. It includes not only the territories of the Galla and Somali, but also those highlands to the south of Abyssinia, where little progress has been made since the visit of D'Abbadie to Kaffa in 1843. There are commercial as well as geographical motives for opening up these almost unknown highlands. When I was at Senafe, in Abyssinia, a merchant arrived from Kaffa or Enarea with donkeys laden with coffee. I had an interesting conversation with him, Dr. Krapf acting as my interpreter. The man said that he had crossed the whole of Abyssinia to find a market for his goods, and that he was on his way to Massawa. We afterward heard that he was robbed and murdered in the Dagonta Pass; so that he never reached his market. This incident has always given me a special interest in the highlands south of Abyssinia; and parts of them have recently been visited by Italian travellers. Chiarini and Cecchi made their way from Shoa to Kaffa. Soleillet reached Kaffa in 1882, Borelli explored the sources of the Hawash in 1888, and reached the Omo flowing to Lake Rudolf, and Dr. Traversi examined the upper Hawash, and Dr. Stecker reached Lake Zuway. The interesting lake district to the south of Shoa is probably most accessible from the north. But assaults should be made on the southern extremity of the great Abyssinian Mountain plateau from the east or the south, by expeditions starting from Kisimayu or Lake Rudolf. Mr. Chanler, with Lieut. Höhnel and Capt. Bottego, who are at present in the field, may possibly solve the problem of the sources of the Jub, but even if

they do succeed there will still remain splendid opportunities for future expeditions.*

The Italians have recently made great efforts to ascertain the geographical features of the Somali country. Signor Bricchetti-Robecchi, especially, has travelled along the whole coast from Mukadisho to Allula, and has also crossed the Somali country from Obbia on the shore of the Indian Ocean to Berbera on the Gulf of Aden. We had the pleasure of welcoming this ardent explorer in the autumn. He had previously written a charming book describing his visit to the oasis of Jupiter Ammon.

The country west of the Jub lies within the British sphere of influence, and the interests of geography, no less than those of commerce, make it desirable that its exploration should be undertaken by British travelers. As soon as friendly relations can be established with the Somali and Galla living at the back of Kisimayu, an expedition into the country of the Borana Galla ought not to meet with insuperable difficulties. Camels, horses, and donkeys are procurable there, so that the work of explorers would be much facilitated. A depot might be established on or near Lake Rudolf, a district which is said to be rich in ivory, and relations might then be established with the tribes intervening between that lake and the highlands south of Abyssinia, including Kaffa and Enarea. Exploring journeys both from the Shoa country to the south, or northward from Lake Rudolf, would lead to a region which, although the last to be taken in hand, is certainly one of the most interesting in the interior of Africa.

Outside the regions just referred to we may be said to have obtained a fair knowledge of the general geographical features of the African continent. Much detail remains to be filled in, and much of the work, executed in a hasty and superficial manner, requires to be done over again. There are also regions of great interest which have been visited, but which will well repay detailed examination. The mountains of Ruwenzori were discovered by Stanley, and have since been passed on the west side by Stuhlmann. Capt. Lugard, whom you had the pleasure of welcoming from Uganda in the last session, was the first to pass them on the eastern side. These mountains and the country between them and Lake Tanganyika comprise a piece of work which Mr. Scott Elliot has just set out with the intention of carefully executing. Most valuable results may, I think, be anticipated from his labors.

Excellent work of the same character has just been completed by our correspondent, Dr. Gregory, on Mount Kenia, and we anticipate a most interesting paper from this accomplished explorer in the course of the session.

Many of the itineraries which crowd and fill up our maps are based

* Capt. Bottego has since returned to Europe.

upon very imperfect materials. Mr. Ravenstein, whose unrivalled knowledge of all that concerns the mapping of Africa is well known, has pointed out to me the want of reliable scientific observations even on routes which have been traversed several times. It is not possible to lay them down on a map with confidence in consequence of these deficiencies. The Victoria Falls of the Zambesi, for instance, have been visited by scores of travellers, but their exact geographical position is still uncertain. Careful astronomical observations have never been taken there. Then, again, the statements as to the height of Lake Ngami above the sea actually vary between 2,260 and 3,700 feet. The Tioge, which enters that lake on the north, has been repeatedly ascended, but observations for latitude have never been taken. Similar instances of opportunities neglected might be adduced from all parts of Africa, the most deplorable one being that of the now abandoned Egyptian Sudan, where an extensive net of telegraphic wires was never utilized for determining the longitudes of Khartoom and other places of importance.

On the other hand, we must remember the admirable work done by our distinguished gold-medallist, Mr. O'Neill, in fixing the position of Blantyre. Equally careful observations have been taken by the Belgian officers in the basin of the Congo and on the shores of Lake Tanganyika. Nor must I fail to record the good work of the members of the Anglo-Portuguese, Anglo-French, and Anglo-German boundary commissions, and of the officers of the Royal Engineers who carried out the surveys for a proposed Mombasa-Victoria railway. We must recognize established facts. It is the work of scientific and carefully trained explorers that we now need in Africa. The time for desultory exploring expeditions is past. Some parts of Africa, including Algeria and Tunis, Cape Colony, Natal, and Eritrea are now actually being surveyed. An extension of such surveys, on the system proposed by Col. Trotter at the Cardiff meeting of the British Association, to other districts already occupied by Europeans is much to be desired. In the end they would prove cheaper than repeated expeditions yielding imperfect or unreliable materials for the map-maker.

Their extension over the greater part of Africa can not of course be thought of for many years to come. But I believe that it would be quite possible to drive certain carefully selected trunk lines across the continent which would serve as bases for all future exploration, and which would enable us to utilize existing materials far more efficiently than can be done at present. The positions of the main stations on these trunk lines would be carefully fixed by astronomical observations, and there should be a number of meteorological stations supplied with standard barometers, so that we may be able to compute our aneroid observations with some confidence in the results.

Such is the work of the future as regards the African continent. There are two great areas of the Sahara to be discovered. There is Wadai

to be explored. We hope that a well-equipped English expedition will, before very long, set out from a base on Lake Rudolf and penetrate the highland regions south of Abyssinia. We also hope to receive much valuable geographical information from the contemplated work of the Hausa Association. There are numerous pieces of local exploration, such as the work undertaken by Mr. Scott Elliot in the Ruwenzori, which are both interesting and important. Lastly, there is the establishment of lines of fixed positions and of meteorological stations which ought to be kept steadily in view by us and pushed forward as opportunity offers. This is the pioneer work which will keep well in advance of the regular surveys. The pace of African discovery, during my time, has been fast and furious. Hereafter it will be more steady and the work will be more scientific. We are proud, as a nation, of the illustrious men who, in the face of appalling sufferings and hardships, and in spite of what might well appear insuperable difficulties, have supplied us, in a comparatively short number of years, with a general knowledge of the interior of Africa. We shall have to ask for equally high qualifications as travellers from those who will, in the future, emulate the examples of Livingstone and Burton, of Speke and Grant, of Cameron and Stanley, and also for scientific attainments of a high order. That the right men will come to the front, who can doubt? Some, indeed, are already in the field. We must not, however, forget the warning voice of my illustrious predecessor, Sir Bartle Frere. "No country," he said, "possesses the best raw material in such perfection as Great Britain. The strong physical constitution, the buoyant energy, the keen power of observation, the good-humored indifference to opposition and danger, the determination not to be beaten, are more common among our youth, more lasting among our seniors, than in most other races. But this very abundance of natural gifts is apt to give us a dangerous contempt for artificial culture. How often have our working geographers lamented the neglect of systematic training by some of our most enterprising travellers." These wise words were addressed to you twenty years ago, and I believe they were taken to heart. Our young explorers now pay much more attention to their scientific training than they did formerly. There is plenty of important work and plenty of very hard work in Africa still, and I am confident that Britain will produce the right men to do it, and to do it well. If there are sucking Wellingtons and Nelsons among us, there are also sucking Burtons and Livingstones. The magnificent raw material surrounds us, and the men who possess the physical advantages enumerated by Sir Bartle Frere will surely add to them the needful scientific knowledge when they find that they must qualify to become good explorers. As our country has produced great African travellers in the past, so she will send them forth in the future. As long as there is work to be done, I say again that there will be no lack of volunteers.

In the continent of Asia British geographers have been very active

during the present century. They have made a trigonometrical survey of India, and we know what those few words signify, what high scientific attainments were required, what hardships and dangers had to be encountered, what heavy loss of life was entailed, and we also know how fruitful were the results. The names of Rennell, of Everest, of Waugh, of Montgomerie, and of our eminent colleagues Gens. James T. Walker and Sir Henry Thuillier, will forever occupy very honorable niches in our geographical temple. British explorers have also surveyed and mapped Mesopotamia and Syria, Persia and Afghanistan; they have navigated the Chinese rivers, penetrated over the passes of the Himalaya, traversed the deserts of Manchuria and Turkistan, and discovered the source of the Oxus. Still they have left a great deal for their successors to do.

Perhaps the most interesting and important unknown Asiatic region is the southern part of Arabia, from Yemen on the west to Oman on the east, and between the sea coast and the states of Nejd in the interior. This unknown region is upward of 450 miles in extent, both in length and breadth. Hadramaut, with its lofty mountains and cultivated ravines, its settled population and historic past, is almost a sealed book to us. The little we know is derived from the narrative of journeys made by Baron von Wrede in 1843, and from the more recent excursion of Col. Miles in 1870. Wrede's stories of Himyaritic inscriptions, wild mountain passes, mysterious quicksands, and terraced cultivation only quicken our longing to know more. Hadramaut, like the Antarctic continent, has been totally neglected by us for half a century. I am happy to be able to announce to you that our accomplished associates, Mr. and Mrs. Bent, accompanied by a Mohammedan surveyor from India and other assistants, are about to undertake the exploration of this practically unknown region. The excellent work they have already accomplished gives us the assurance that when we welcome their return we shall find that they have brought back a rich store of valuable and interesting information.

Leaving Arabia and Syria, we find much work yet to be done in Asia Minor. The most important unexplored field includes the upper valley of the Euphrates and Eastern Cappadocia, and toward this part of the work our society has already made a liberal contribution. Next, turning our attention to Persia, we come to a country which has been explored and reported upon by many of our countrymen since the days of Sir John Malcolm, and which has now, thanks to our colleague, Mr. Curzon, been admirably mapped. Yet even here, as I am informed by Mr. Curzon, plenty of useful geographical work remains to be done; while a good deal of information that has been collected by officers dispatched by the intelligence department at Simla continues to be "secret and confidential." Thus there are several gaps which it is in the power of private travelers to fill in, so that Persia still affords an interesting and far from exhausted field for geographers.

Entering from the west, although the frontier province of Azerbaijan has, in its northern half, been systematically explored and mapped by Russian surveyors, in its southern parts and on the Turkish border attention might usefully be paid to the Persian Kurds, both nomad and sendentary, the former mostly in the mountains, the latter in the triangle of which the three points are Suj-Bulah, Bijar, and Sinna. Farther south, Luristan still remains unexplored in many parts, especially in the western subdivision called Pusht-i-Kuh, the home of the Feili Lurs. Since Sir Henry Rawlinson and Sir A. Layard were there fifty years ago these regions have been almost unvisited. Again, to the west of the route, from Tehran to Ispahan, there is a number of small districts which are very imperfectly known; while west of the road from Ispahan to Shiraz there is an absolute blank on the thirty-third parallel, between Kumishah and Yezd. Farther south, the Bashakerd province and Persian Baluchistan are very little known and largely unexplored, and in Luristan there is a blank space on the maps between the coast range and the caravan route from Faizabad to Lar. So that it will be seen that there is a great deal to which a young geographer might devote his energies in Persia. The same may be said of Baluchistan, where, between Kharan and the Mekran coast, except along the old Kafilah route from Lus-Bela to Panjgur (which was traversed by Sir R. Sandeman in 1890), the map is almost a blank.

Parts of Afghanistan are very dangerous for Europeans to be employed in, and our knowledge of the mountain ranges between Kabul and Herat, which are occupied by the Hazara and other tribes, is most inadequate. Our ignorance of Kafiristan is complete. We still know nothing whatever of that interesting country, and its exploration is very desirable. Officers have been on its frontier—Col. Tanner on the side of the Kunar River, my old friend, Sir William Lockhart, on the north, and the late Mr. McNair from the side of Chitral. But the country itself, from the passes of the Hindu Kush to the banks of the Kunar, is unknown. Its exploration is one of the great geographical achievements that remain to be done in Asia. The results would be important both from a political, a geographical, and possibly a commercial point of view, and there could be few nobler ambitions for a young aspirant than to be the first explorer of Kafiristan. In southern Afghanistan much also remains to be done, as, for instance, in the tracts to the west of the British frontier, between the Zhob and Kurram valleys.

The Pamir table-land has been largely explored by several European travelers; but there is plenty of room for further work, and a systematic survey of the whole region would be a valuable contribution to geography. Farther to the east the plains of Turkistan have been elaborately explored, and are sufficiently well known. The mountains and hills to the south, however, being spurs from the Mustagh-Himalayan ranges, are very imperfectly understood. It is doubtful, for

instance, whether the Yarkand River, which rises in those ranges, flows some distance westward before it enters the plain, or whether it breaks through the mountains 30 or 40 miles to the east and proceeds direct to Yarkand. A fairly accurate survey of the northern slopes of the Himalayan Ranges and the adjoining portions of eastern Turkistan is much needed, although a great deal of good work has quite recently been executed in the loftier parts of those ranges.

The recent journey of Mr. Conway among the glaciers and higher passes of the Mustagh-Himalayas is an example of what the courage and skill of an able private explorer may do under the most difficult circumstances. Starting from Hunza and Nagar, he surveyed a considerable area of country at great altitudes, and he has been able to correct and add to the survey of this region, which was executed by Col. Godwin Austen. Fellows of the society have already listened to Mr. Conway's graphic narratives, and before long his painstaking and minutely accurate map of one of the most remarkable portions of the Himalayan glacier region will be in your hands. In the same region, but still farther north, officers of the Indian Survey are pushing their observations, and we may hope in due time to be furnished with the results. Another surveyor, Mr. Senior, has done much valuable work under circumstances of unusual difficulty, among the higher ranges of Kula and Lahaul. His merits have been recognized by our council, and he has been awarded our Murchison Grant.

Farther to the east, along the Himalayan chains, the kingdom of Nepal covers a tract of country about 500 miles long and 100 miles broad, lying between the crests of the mountains and the British frontier. This is still almost a blank upon our maps. Europeans, except a few officers at the capital, are debarred by treaty from entering Nepal so that the country is very imperfectly known. The passes from Nepal into Tibet have a special interest for us, because the only great army that has invaded India since the commencement of British rule in Bengal marched through one of them, the Kirong Pass, and so descended from the valley of the Tsanpo into Nepal. It has never, I believe, been visited by any European.

Lhasa, the capital of Tibet, has never been visited by any Englishman since the days of Manning. There is also a vast and wholly unexplored region of Tibet on the northwest, between the parallels of 34° and 36° and the meridians of 82° and 90°. It lies between the explorations of Capt. Bower on the south side and those of Col. Pevtsof and M. Bogdanovich on the north. In southwest Tibet there are also great belts of unknown country between the routes of Pundit Nain Sing from Ladak to Lhasa, and his route along the upper course of the Yaro-Tsanpo River; also between that river and the crests of the Himalayan ranges, which form the border of Western Nepal. The course of the Tsanpo and the adjoining country on both banks are well known as far as the meridian of 93°, and fairly well, but with some uncertainty, to

94° 10′. But from that point down to its entrance into the Assam Valley, under the name of the Dihong River, it is wholly unknown. So also is the country eastward up to the meridian of 97°—a region which is probably the basin of the tributaries of the Dibong River, which flows into the Lohit-Brahmaputra a few miles above the point where the latter river joins the Dihong or Tsanpo.

The great rivers of central and eastern Tibet—the Giama-Nu-Chu, the Lantsan, and the Di-Chu—are fairly well known in parts; but there are considerable portions of the first river, more particularly, which need further exploration. There is considerable uncertainty whether, below where there is a ferry on the road from Dayul to Kima, the Giama-Nu-Chu flows southward as the source of the Salwin, or south-westward and is the principal source of the Irawadi. This is a geographical problem of great interest, and offers a splendid opportunity for ambitious young explorers to win their spurs. This whole region of complicated mountain and river systems, which still conceals the sources of the great Burmese streams, urgently calls for bold and hardy explorers to disentangle it. It is the borderland of several races, mostly broken up into minute tribal divisions, which present the same interest to the anthropologist as their country does to the geographer.

In Burma itself much information is still needed to complete our knowledge of its geography; but this desideratum is being systematically attended to by the Indian survey department. In Siam Mr. McCarthy has recently constructed a map, and the trade routes between Chieng Mai and the Upper Mekong have been traversed by Holt Hallett, Carl Boch, Archer, and others. But the region lying to the south, between the Menam Valley and the lower Mekong, is almost unknown to Englishmen. A thorough acquaintance with the country on the western side of the Mekong is very desirable: such as the cis-Mekong parts of Luang Prabong and of Nan, and the parts intended to be opened up by the projected railway from Bangkok to Korat. I may here mention that a valuable communication has just been received from Mr. H. Warington Smyth, describing his voyage up the Menam and his journeys in the mountainous country to the west of the Mekong. Our young correspondent is a son of our former colleague, the late Sir Warington Smyth, and a grandson of our President Admiral Smyth, to whom the society owes so much, and was one of our seven founders. Mr. Warington Smyth's narrative is of geographical value and is charmingly written, and it is pleasant to find that in this instance the geographical mantle of my distinguished predecessor has so worthily descended on his grandson. In the Malay Peninsula there is also much to be done; and Mr. Lake has just brought home some good surveying work of previously unexplored country in the territory of Johore. But we have to deplore the death of Mr. Becher, who unfortunately lost his life in a river in the southern part of the Malay Peninsula just

after he had entered upon what promised to be a useful piece of geographical work.

Passing over the great Empire of China, which has been traversed in numerous directions, and the geography of which is tolerably well understood, we come to Korea. In this peninsula, which until lately had scarcely been visited, the pack roads between the principal towns are now pretty well known, but there remain a number of routes on the western side, from Seöul down to the south coast, and on the east side between Gensan and Fusan, which Mr. Cuzron informs me have either not been traversed in modern times or are wholly unexplored. There is very great need of a survey and map of Korea, and, apart from the pack roads, the mountainous parts of the country are quite unknown. There is thus very considerable scope for geographical enterprise in this great peninsula, which may be looked upon as one of the numerous allurements which the unknown parts of the world present to the explorer.

Leaving the great Asiatic continent, and turning our attention to the mass of islands to the south, and stretching away eastward to the Pacific, we shall find that the most important future work will have to be done by the hydrographer rather than by the geographer. Doubtless there are many unreported reefs and shoals, and others whose recorded positions require verification. Yet when we think of the splendid work of Mr. Wallace in the Malay Archipelago, and ot the lonely residence of Mr. Forbes on Timor Laut, there can be no doubt that much is also left for the explorer to do on land among those lovely islands. Sir William Macgregor will steadily proceed with the examination of British New Guinea, and will encourage all well-conceived schemes of discovery. Mr. Woodford tells me that, in his opinion, a properly equipped expedition would have little difficulty in passing from the headwaters of the Fly to those of the Empress Augusta River, and so crossing New Guinea in its broadest part. Meanwhile the interior of Dutch New Guinea is a complete blank—another of the vast tracts which await discovery. Here there is an extensive range marked on the maps as the Charles Louis Mountains, and attaining a height of 16,000 feet. The particular exploration of this range would offer work for geographers and naturalists for many years to come. Another interesting piece of work for a young explorer to undertake would be a definite solution of the question whether a passage exists right through the supposed isthmus from Maclure Gulf to Geelvink Bay, as has been reported. More knowledge of the islands to the north of New Guinea is also needed, where the natives present the chief obstacle to exploration. In the Solomon Islands, Mr. Woodford was successful in visiting the interior of Guadalcanal, but Bougainville Island is still absolutely virgin ground, and I am informed by Mr. Woodford that there is a most interesting elevated coral lagoon to the north of the island of New Georgia, which has hitherto been unde-

scribed; while Rennell and Bellona Islands, to the south of the Solomon group, are said to be elevated about 400 feet above the sea, yet exclusively of coral formation. The natives are Polynesian, not of Melanesian race, and they would certainly well repay a visit. The whole question of the mingling of Polynesian and Melanesian types on these groups of islands calls for careful investigation, as well as further study of the formation of coral reefs. Mr. Woodford suggests that it would be desirable. if funds could be obtained for the purpose, to make an experimental bore with a diamond drill upon some island of purely coral formation, situated in very deep water, and as far removed as possible from any high land. He thinks one of the islands of the Gilbert or Ellice groups would be suitable for the experiment.

It is unlikely that there are now any undiscovered islands in the Pacific, although I well remember the time when we fully expected that there might be, and when we were ordered to enter in the deck log, during our watches, the visibility of distant objects. Thus our tracks formed belts varying from 10 to 15 miles wide, within which no new islands were to be found.

Australia has now been explored in its whole extent. The work was watched with the deepest interest and sympathy by our society; and no less than twelve Australian explorers have received our gold medal. Queensland, New South Wales, Victoria, and South Australia proper are thoroughly well known; but in western Australia there are still large isolated tracts of the country in the interior which are unexplored. The most important lies east of the one hundred and twentieth meridian and between about 21° and 24° south. Mr. Ernest Favenc points out that the important geographical fact to be determined by an examination of this tract would be the settlement of the question whether Sturt's Creek again reformed, after having been for a time lost. Probably some patches of pastoral country and some unconnected water-channels and saline swamps would also be found. Mr. Favenc considers that the geographical problem to be worked out in Australia, during the ensuing years, is the evolution of a last river system, which will fill up the gap between the heads of the west coast rivers and the Lake Eyre system. It is not likely that such a system will exist in anything more than a fragmentary form, but certain fixed drainage rules peculiar to that region may be found to exist which would dispel the present notion that the creeks there run at random to all points of the compass. The northern coast regions are now well known and fairly well settled throughout by sheep farmers; and the gold discoveries in the southwest of the continent are extending inland and may reach the unexplored space, as belts of auriferous country are known to exist across the interior.

In New Zealand, as Mr. Douglas Freshfield has recently pointed out, a glorious field is open for the mountaineer, for the so-called Southern Alps have the glaciers of the Alps, the forests of the Caucasus, and the

fjords and waterfalls of Norway all brought into close juxtaposition. Stirred by the success of Mr. Green's ascent of Mount Cook, the young New Zealanders have formed an Alpine club, under the presidency of Mr. Harper. The proper line of exploration would be to continue establishing huts on both sides of the range, so that the relation and divergences between the west and the east flanks may be fully investigated. Hitherto the east side has been principally explored.

Australia now has geographical societies of her own, active and learned bodies, which are doing good work. It has been suggested by Baron Sir Ferd. von Mueller, and his idea has been adopted by his colleagues in Australia, that, with the object of establishing close affiliation between the parent society and all the branches, our council might annually elaborate a series of questions for transmission to our colonial and provincial colleagues. Such questions might refer to tidal observations, oceanic currents, the most important spots for additional hypsometrical data, accurate determination of longitudes, and the settlement of new projects for exploration. I am quite of opinion that this suggestion is well worthy of the consideration of our council.

The New World, including the two continents of North and South America, has been in process of discovery for the last four centuries. The nearer parts had to be settled before the more distant parts could be explored. The whole of the coasts, indeed, have been surveyed with more or less completeness, and the U. S. Coast Survey is a monument of rigorous accuracy. But much of the interior is still unknown or very partially explored. This is certainly the case in the Dominion of Canada, and Dr. George M. Dawson recently said that we are far from having acquired even a good general knowledge of fertile lands with a rigorous climate which will only yield hardy crops, although comparatively little of the region capable of producing wheat is now altogether unknown. Then there are vast tracts of unknown country where possible mineral wealth would be the only material incentive for their exploration.

Within the Arctic Circle there is an unknown area covering 9,500 square miles between the eastern boundary of Alaska, the Porcupine River, and the northern coast. Another area of 32,000 square miles of considerable interest, and probably containing the head waters of the White and Tanana rivers, lies west of the Lewes and Yukon, and extends to the Alaska frontier. There is an unknown tract of 27,000 square miles between the Lewes, Pelly, and Stikine rivers, which lies on the direct line of the metalliferous belt of the Cordillera. Between the Pelly and Mackenzie rivers there are 100,000 unknown square miles, including nearly 600 miles in length of the main range of the Rocky Mountains. Our back grant testimonialist, the Abbé Petitot, has made a short journey into the northern part of this area from the Mackenzie River, but otherwise no published information exists respecting it. Another Arctic area, between the Great Bear Lake and the northern

coast, covering 50,000 square miles, is also unknown, and yet another of 35,000 square miles south of the Great Bear Lake, except for the journeys of the Abbé Petitot and Mr. Macfarlane. Farther south there is an unknown tract of 81,000 square miles between the Stikine and Liard rivers to the north and the Skeena and Peace rivers to the south, and another of 7,500 square miles between the Peace, Athabasca, and Loon rivers. An unexplored area south of the Athabasca Lake is 35,000 square miles in extent.

Turning again to the Arctic regions, there is an area of 7,500 square miles east of the Coppermine and west of Bathurst Inlet, and another of 31,600 square miles between the Back River and the Arctic coast. I quote Dr. Dawson's figures, but I do not forget the work that has been done by Mr. Warburton Pike from the love of adventure, sometimes living on cariboo, at others on musk oxen, at others on cachés formed when game was abundant, and at others suffering from starvation. With no companions, save a few Indians, he has crossed and re-crossed the barren lands of America. We next come to the vast unknown tract of 178,000 square miles between the Back River and the west coast of Hudson Bay, part of which was wandered over but not mapped or explored by Hearne in 1869–1872, and I believe it has also been traversed by Mr. Pike. There are smaller unknown areas to the south of Hudson Bay, while the whole interior of Labrador, covering 289,000 square miles, is entirely unknown beyond the short routes of Prof. Hind, Mr. Low and Mr. Holme, and Pére Lacasse. This tract is believed to be more or less wooded, and in some parts with timber of large growth, but the practical utility of its future exploration will probably be derived from its metalliferous ores. Dr. Dawson sums up his enumeration of unknown areas with the calculation that out of the 3,470,287 square miles which form the area of the Dominion of Canada, 954,000 square miles, at the very least, are entirely unknown. In looking forward to the future examination of these areas, Dr. Dawson remarks that the explorers should be possessed of scientific training and be able to make intelligent and accurate observations. The work of Mr. Green and Mr. Topham in the Selkirk range of British Columbia has been excellent, and it has brought to our notice a region of the greatest orographic and geological interest, part of which is still unmapped and unvisited.

In the United States there is much that remains to be done in Alaska, although the labors of Mr. Fred. Whymper, Seton-Karr, Topham, Nelson, and Ogilvie have thrown light on the alpine regions with their extensive glaciers, which culminate at Mount St. Elias and on the basin of the Yukon. In the vast territory of the Union itself surveying work of a more exact and rigorous character is making progress, and the admirable coast survey from the Bay of Fundy to the mouth of the Rio Grande on the east side and from the Strait of Juan de Fuca to San Diego on the Pacific side is completed. Its merits were cordially recognized by this society when our gold medal was conferred upon

Prof. Bache in 1858. Inland topography however owes most to the geologists, for Powell in the Rocky Mountains region, Hayden in the territories, and Clarence King on the fortieth parallel have been obliged to make their maps as they proceeded with their geological investigations. The triangulation in the interior of the States was commenced late and its progress has been slow.

There is a great deal of work for an explorer in Central America, where our associate, Mr. Maudslay, has done so much excellent service, and where we are also indebted to the researches of officers from British Honduras. But it is in South America that the most extensive unexplored regions are still awaiting the visits of scientific travelers. Many parts of the Columbian Andes need exploration, as well as the basins of the great rivers Japura and Putumayo and some of the smaller affluents of the Amazon, such as the Pastasa, Morona, Santiago, Napo, and Tigre. There is an enormous tract in Colombia, bounded by the slopes of the Andes on the west, by the Orinoco and Rio Negro on the east, on the north by the Meta, and on the south by the Uaupes and Japura, which is practically unknown. I have called attention to this region on previous occasions in the hope that some one would undertake its exploration. For it was here that the old conquerors of the sixteenth century, without watch or compass, sought for El Dorado. Another unknown region lies between Guiana and the Amazon, while the rivers Jurus, Jutay, and Teffé are unexplored. The admirable survey of the great River Purus and its main tributary secured for Mr. Chandless the gold medal of our society, but many of the affluents of the Beni, flowing from the Andes of Cuzco, still require scientific exploration.

The mighty Cordilleras of the Andes have only been very partially examined. From Mr. Whymper's delightful book, with its superb illustrations, we learnt much about the famous peaks of Ecuador, and some of our ideas received correction; while the surveying labors of Mr. Wolf in the same region have led to the examination of the little known provinces between the Andes and the Pacific and to the production of a most valuable map of Ecuador. In Peru the learned president of the Lima Geographical Society, our honorary associate, Dr. Luis Carranza, has admirably described the geography of some of the provinces of the Andes. Still there is an undescribed Andean region, comprised in the provinces of Lucanas, Parinacochas, Cangallo, Aymaraes, and Cotabamba, and in the coast valleys and deserts between Nasca and Lajes. Forbes, Minchin, and Weiner have ascended Illimani and Illampu, but the mountains of the coast range farther south are almost unknown, and the great peaks of Sajama and Pallahuari are still unmeasured.

Indeed, the whole orography of western South America is very imperfectly understood, and would well repay further scientific examination. The great rivers of the Gran Chacu, flowing from the Bolivian Andes

to the Paraguay, are still incompletely explored, especially the more northern streams. Capt. Page read a most interesting paper on the subject at our meeting on January 28, 1889. In the discussion which followed I mentioned that the Gran Chacu was one of those regions to which geographers might point when they were tauntingly asked what was left for them to discover. Capt. Page has since lost his life—a martyr to science and to duty. His work will be taken up by others where he has left it. The exploration of these streams, especially of the Utuquis, and the region through which they pass, must needs be completed; for some day they will form great fluvial highways of commerce. Farther south there are tracts needing examination, especially along both sides of the dividing line between Chile and the Argentine Republic, as well as in Patagonia. The government of Neuquen is one of these, a region with mountain slopes covered with beech (*Fagus Antarctica*) and pine (*Araucaria Brasiliensis*) forests and with active volcanoes along its summits, while its rocks abound in fossil shells and wood and send forth thermal springs. The belief that in this district the Collon-cuá (called in its upper part the Mumini), flowing to the Atlantic, has its source in the same lake as the Rio Bio, flowing to the Pacific, would be an interesting point for an explorer to clear up. I rejoice to find, from an interesting memorandum furnished me by Capt. Don Benjamin Garcia Aparicio, of the Argentine corps of engineers, that exploration is being zealously promoted and encouraged by our sister geographic society at Buenos Ayres.

We have now made a general survey of the unexplored and undiscovered *lands* of our globe. But the work of geographers is by no means confined to the land.

It is nearly forty years since Maury published the first edition of his "Physical Geography of the Sea." He was the founder of a new and most interesting branch of our science, which treats of the ocean depths, of the currents and temperatures of the sea, of its biology, and of the surface of the ocean bottoms. In 1855 this was a new field of research, when the *Arctic* and the *Cyclops* were running their first lines of soundings across the North Atlantic, and when Brooke and Wallich were inventing the first apparatus for bringing up samples from great depths. Since then, through the labors of scientific officers of several nationalities, the gates of this new field have been opened wider and wider. The result is due to the invention of improved appliances and to the persevering work of deep-sea soundings and dredgings as well in narrow seas as in the great oceans. This of course is not work for individual explorers, but rather for the governments of maritime nations. Yet I would urge upon the attention of naval officers, of officers of the naval reserve, and of the mercantile marine that they all have frequent opportunities of adding to our knowledge, and of doing useful work in forwarding the examinations of the depths of the sea and in contributing to our knowledge of meteorology.

An immense mass of work remains to be done to enable us to have even a rough and general knowledge of the ocean depths. Additional lines of soundings are needed in all directions, especially in the Southern Ocean and in the central Pacific, to bring out their general configuration. We now have a rough idea of the areas of greatest depths, the greatest of all having been obtained off the coast of Japan by the *Tuscarora* in 4,655 fathoms; but the soundings of the *Challenger* between St. Thomas and Bermuda and of the *Egeria* in the Pacific come very near to it. The discovery of the very greatest ocean depth will be most interesting, but it would be still more so to discover and map the submarine ranges and peaks to within, say, 500 fathoms of the surface. I remember that when the *Valorous* ran a line of soundings across the North Atlantic in August, 1875, we got 1,860 fathoms on one day, 1,450 on the next, and only 690 on the next, bringing up pieces of black volcanic stone. On the two following days the depth increased to 1,250 and 1,485 fathoms. Here there was clearly either a volcanic peak or a ridge; and wherever these are known to occur I think that it would be very desirable to explore the surrounding ocean bed and ascertain their extent and character. We want also the establishment of a more complete study of the system of ocean currents by a very extensive use of floats adapted to swim at various depths, and also a fuller investigation of the temperature and density of the water surrounding the shores of all the continents. The work hitherto done in the North Sea and the neighboring Atlantic is practically confined to the summer months, and a detailed examination at all seasons is needed. Such work is now being done under the auspices of Profs. Petterssen, of Sweden, and Mohn, of Christiania, Krümmel, of Kiel, and the fishery board of Scotland. We also require a determination of the isotherms and isobars on land and sea at all seasons, which will primarily involve prolonged observations in the South Polar region, and a more complete knowledge of the variation of atmospheric pressure with height, and its independent variation in different horizontal planes. Such an investigation embraces the whole question of the use of the barometer or boiling-point thermometer in measuring heights.

This will conclude my enumeration of the geographical desiderata in the field. It is a long and formidable list, affording work for many decades of years to come. But many of my associates know very well, and the rest must now clearly understand, that it is by no means an exhaustive list, but only such an enumeration as our limited time will admit of our making, merely a rough general survey of the work in the field that remains to be done.

The work of explorers is co-ordinated and rendered useful in many ways by geographical students, whose valuable labors desire equal attention and encouragement. There are many geographical problems which must be solved as well by the examination and intercomparison of the work of numerous explorers in different regions as by the care-

ful study and application of the achievements of the devotees of our science in past centuries. The advance and extension of geography depends as much upon its students and scholars as upon its discoverers and explorers. Comparative geography is indeed one of the highest branches of our science. By identifying sites, comparing descriptions written long ago with the actual surface of the ground, and by demonstrating the changes which have taken place within historical times, it is an indispensable auxiliary to physical geography. We shall, I am sure, all be glad to receive the results of the investigations of our Oxford travelling scholar, Mr. Grundy, who has compared the narrative of Herodotus with the actual ground where the battle of Platæa was fought. Comparative geography also enables us to comprehend the gradual evolution of our science through the discoveries and lifelong studies of a long series of devoted men during a succession of ages. Such knowledge is of the deepest interest. We therefore welcomed, in 1891, Dr. Schlichter's ably reasoned paper on Ptolemy's topography of eastern equatorial Africa, and we shall be glad to receive further results of his researches. Mr. Ryland's long and careful bibliographical and mathematical study of Ptolemy and his laborious corrections and verifications have also resulted in an important addition to Ptolemaic literature.

The spirit in which geographical students enter upon their researches and the methods they adopt have a special interest at a time when the educational efforts of the society justify the expectation that their numbers will soon increase. Dr. H. S. Schlichter, who has already communicated the most interesting paper on Ptolemy's geography of Africa—to which I have just alluded—has explained to me his system of investigation. He not only uses history for the solution of physical phenomena, but also resorts to physical facts and observations for solving questions of historical geography. By looking at the problem under consideration in all its bearings and the various ways which seem to lead to its solution an insight is obtained into the nature of the questions we have to deal with and into the trustworthiness of the sources of our information. Such studies lead from one problem to another. They open up new questions and lines of research, and not only connect physical and historical facts of all times and ages, but also join our own minds and thoughts with those of men who lived and worked centuries before us. Hardly any branch of science is of greater interest in this respect than comparative geography, because wherever we turn we discover links which connect the development of our race with the changes on the surface of our planet.

Dr. Schlichter is now engaged in studying the desiccation of parts of Africa, and he has, with great labor and research, drawn a series of sections across that continent. The subjects, in physical geography, which offer themselves for the investigation of the student are, indeed, as numerous as they are fascinating. The process of denudation of

erosion and of transportation may be studied and compared; while, as Prof. Lapworth has pointed out, the agencies which rule in the processes of upheaval and depression are still almost entirely unknown to us. The professor's address, delivered at Edinburgh last year, on the crests and troughs which succeed each other on the earth's surface in endless sequence, of every gradation of size, of every degree of complexity, offers much matter for reflection to the student of geography. The geological fold, as described in Prof. Lapworth's address, should receive the attention of physical geographers who can take advantage of their great opportunities as explorers and as students, by investigating as well the simple fold, often under altered conditions caused by erosion, as the tangential pressures and other influences that have been at work on it. Thus we should combine with geologists in working out nature's problems while we study the earth's past history in order to understand its present condition; for, although the limits between the sciences of geography and geology have been clearly defined, the difference between our studies consists rather in our methods and objects than in the materials on which we work. We are therefore prepared to give a cordial welcome to Mr. Oldham's promised paper on the present condition of the surface of British India, as explained by its former geological history.

If a competent acquaintance with geology is required for an accomplished geographical explorer, a knowledge of biology is equally desirable. For instance, the study of the fauna of inland lakes and rivers has been pointed out by Darwin and Peschel as important in connection with many problems in physical geography. It is two thousand years ago since Eratosthenes, who presided over geographical science at Alexandria, drew scientific conclusions from the fact that certain shells were found near the oasis of Jupiter Ammon. It was by the study of the fauna of large lakes in North America and in Asia that their marine origin was established, while we deduce the former existence of lands now submerged from the comparison of fossil animals. Plants have acted an equally important part, both in effecting the condition of the earth's surface and in revealing to us its former history.

I anticipate that such investigations will occupy some of our present and future students and explorers as they have occupied their predecessors; but they will, I trust, always bear in mind that the basis of all geographical work, if it is to be really valuable, is the fixing of positions astronomically. Accuracy and reliability can alone make their work permanently useful. Much attention ought therefore to be given to the handling and adjustment of instruments and to their improvement. Experience in the field often leads to suggestions which bear fruit when they are carefully thought out. Thus there have been several forms of range-finders invented in recent years which might be used in making rough surveys. Both Sir George Airy and Mr. Merri-

field have introduced new methods of computing lunars, and a method of semiazimuths, invented by a yachtsman, is now under discussion. Dr. Schlichter has recommended the use of an apparatus for photographing moon and stars for lunars which is described in the November number of our *Journal*, and Col. Stewart invented another apparatus for surveying by photography. Improvements are sure to suggest themselves to intelligent workers. Maj. Watkin has improved on the aneroid. Several attempts have been made to improve the artificial horizon. Maj. Verner has invented a compass to be used for travelling at night.

Photography now occupies an important place in relation to geography, and a photographic camera should form part of the equipment of all explorers engaged in original geographical work. It is to be regretted that travellers have not taken more advantage of the facilities afforded by the society, as the use of an instrument should be thoroughly mastered before a traveller proceeds on a journey. In photometry it is necessary that objects represented on the plate should be clear and well-defined to facilitate the taking of measurements from them; and this has now become specially important since the invention of the new method of taking lunars.

It is in the direction of the improvement of instruments, cameras, and other appliances used by the traveller, and of methods of observing and computing, that experienced and ingenious men should continue to turn their inventive faculties. Very often an improvement occurs to an observer while using an instrument in the field, which afterwards, by following up the train of thought, leads to the perfection of a practically useful invention. This has been the case from the days of Martin Behaim to those of Leigh Smith.

Many of the rising generation of geographers, whose talents lie in that direction, will also, it is to be hoped, master the beautiful and most useful art of the cartographer, including the work of the compiler and of the draftsman. At present there are none too many in this country. When we reflect on the exquisite specimens of Italian and Catalan *portolani* which are preserved in the British Museum, and on the great geographical interest attaching to early examples of cartography, it is impossible not to regret that we are unable to produce an atlas such as the Berlin Geographical Society brought out last year. There are as yet no adequate opportunities in this country for developing the latent powers of the potential Kretschmers who doubtless exist among our young English geographers, but I trust that every encouragement will be given to those who, in the future, give their attention to this branch of our work.

Turning once more to the qualifications of an explorer, Mr. Galton has suggested to me that the art of geographical description is a very needful one. It is seldom that a country resembles what the visitor has been led to expect from reading recent descriptions of it. It is not

the so-called "word painting," now so elaborately employed, that conveys the most correct picture; but rather pithy epithets and sharp, clear touches. The old writers were often excellent in doing this, with their forcible homely language; and they should be read until some echo of their pure vigorous style has been caught. The necessity for cultivating the describing faculty, and for studying the general principles underlying all good description should be inculcated by those who train men as geographical explorers; for a traveller is of no use if, when he comes back, he fails to convey to others a correct idea of what he has seen.

The various subjects to which a geographical student or explorer can give his attention are as fascinating as they are numerous; and whether he devotes his talents to the improvement of instruments, or to the work of the draftsman and map-maker, or to the manifold phases of physical geography, or to discovery in distant lands, or to the elucidation and illustration of the history and progress of our science, he will alike be furthering and advancing our objects and will have a right to claim our assistance and our sympathy.

We do not invite geographers to enter upon any of these difficult undertakings without being prepared to supply them with a suitable training, and to give them all the sympathy and encouragement in our power. This was not always the case. I well remember that a young officer in command of the Hausa police force came to me for advice, just twenty years ago. He wanted to learn the use of the sextant and artificial horizon. At first I had no answer to give him; but afterward I found out that a widow named Janet Taylor gave the required instruction in the Minories to mates of merchant ships. It was this dearth of the means of learning the work of an explorer that forced my attention on the duty of finding a remedy. Mrs. Taylor was an efficient teacher, I believe, but the Minories are far off, and her single efforts could not supply what was needed. It was then that I submitted proposals that the society should appoint an instructor and furnish the necessary facilities for enabling explorers to learn their work. Our council saw the importance of supplying a great need, and Mr. Coles was appointed to instruct intending travelers in practical astronomy and surveying. My proposal included instruction in geology and biology, and now arrangements are made for teaching what an explorer would need in these branches of knowledge also, as well as in photography. I look upon this as the most successful measure that has been adopted by this society in recent years and the one which has done most to advance the interests of geography. Since Mr. Coles began to give instruction in surveying and nautical astronomy, he has taught 239 pupils, including officers in the army and navy, in the consular and colonial services, missionaries, civil engineers, and private travellers. These instructed explorers have done valuable geographical work in all parts of the world—in Africa, Asia, North and South America, the Malay Archipelago and Pacific

Islands, and in the Arctic regions. Of the 239 pupils, 20 have studied photography, 18 botany, and 10 geology, in addition to surveying and nautical astronomy. It is of the utmost importance that explorers should be thoroughly trained for their work, and their instruction is consequently one of the most indispensable duties of our society.

In this imperfect survey of our geographical *desiderata* I have endeavored to draw the attention of my associates, not only to the extent of unknown country to be discovered and explored, and to the numerous problems and questions of interest which await solution, but also to the duty that is laid upon us—each one of us—to take his share of the task, some by useful advice and co-operation, some by encouragement, all by a hearty determination to work together for one great end—the usefulness and prosperity of our society.

HOW MAPS ARE MADE.*

By W. B. Blakie.

The subject on which I am deputed to address you to-night is what, in the slang of the day, may be described as "a very large order." Though the title seems simple enough, the subject itself is so large and it spreads and ramifies itself through so many arts and sciences, that the temptation to go off from the distinct line of my subject into the different branches that introduce themselves is great, and all these branches are to me so interesting, that I have found great difficulty in confining myself strictly to the story of how a map is made. I have forced myself, however, to stay on the center line of map-making, and I hope, before the evening is over, to give you a clear and distinct idea of the principles on which a map is made, for the subject of my paper is not "How maps are drawn," but "How maps are made;" and I will attempt to show you the naked machinery of the process.

I have often been amazed at the popular ignorance of what would seem to be the very first principles of geography and of map-making, and this has induced me to begin at the very A B C of the subject. I intend throughout this paper to avoid technical phrases and mathematical terms. I have nothing new to tell you; much that I am about to say is known to every person here present, and I ask you to bear with me if occasionally I seem childish in my descriptions.

One thing more I should like to premise, and that is, that in this paper I do not propose to go into any great detail, or to confuse anyone here with the numberless scientific corrections and modifications that have to be made in all scientific calculations. I will speak only on general principles; those who know the science thoroughly will understand the modifications necessary, while those who have not the same advantage will, I trust, be able to grasp the principles of what is shown.

My intention to-night is to show (1) how a spectator finds his position on the earth's surface; (2) how he defines and records that position; (3) how he makes a map from the information he has found; (4) how he fills up the details of that map; and (5) briefly to describe how the map

* Read at meetings of the Royal Scottish Geographical Society in Edinburgh and Glasgow, April, 1891 (*Scottish Geographical Magazine*, 1891; vol. VII, pp. 419, 434).

so made is drawn and printed, and incidentally to show the use of the various tools and instruments employed in these operations.

I assume that we all know that the earth is (roughly speaking) a sphere, spinning round on its axis once in twenty-four hours. Now, if we take up a sphere, like this ball, and mark a spot on it, there is nothing whatever to define its position; no north, no south; nothing to guide us. One point on this sphere is the same as any other point, until we find some reference spot to measure from; but we have assumed that we know that the earth spins round on its axis, and here we at once discover something we can measure from. The ends of the axis of the ball, which we call the poles, are, we see, at rest compared with the rest of the surface of the spinning ball.

Now, this so-called polarity gives us at once two points of reference. Although no one has ever been at either of the poles, the study of the subject for hundreds of years has proved their existence as surely as if the poles had been visited and been discovered marked with upstanding posts. Between these two points, which we call the poles, I can mark a point half-way, which, by spinning the ball in contact with the pencil, I convert into a line called the equator, the equal divider, popularly *the* line. You will observe that this middle line, this equator, is also the largest possible circle on this sphere, and it is from this circle that all measurements and references north and south are made. We see on the globe and on maps a number of other circles parallel to the equator to the north and south of it, and drawn at equal distances, These are called the *parallels of latitude* (or wideness), and they mark certain degrees of *angular divergence* from the equator.

Consider for a moment what this means. In the first conception of them these lines have no specific distance apart, because they really are angular measurements, and it is this conception of them I wish to get hold of. A degree of latitude is not necessarily a number of miles, and until we know the actual diameter of the earth we can not tell what the length of a degree is. It is a proportion of the circumference of a circle, a fractional measurement of it. We may speak of a half, a quarter, of anything, but, until we say what it is a half or a quarter of, the phrase conveys no idea of magnitude. It might be half a mile, or half a kingdom, or half an inch, or half a crown. Similarly, a degree of a circle means nothing so far as length is concerned, until you know the size of the circle, when you can at once calculate, with the proper mathematical knowledge, the numerical value of a degree at the earth's circumference.

Now, having marked these lines on the surface of the earth, we have certain marks on our globe to which we can refer any and every point. It may be said, "Why mark these lines on the map? They do not exist; they are only imaginary." Quite true! But then the first principle of all map-making is to begin with imaginary lines, from which to measure the position of every place on that map; and all such imag-

inary lines are carefully recorded, as we shall see later on, so that they can be accurately laid down at any moment by those who know how to find them. We find them a great convenience, an absolute necessity, indeed, so we leave them drawn on the globe. Imagine a street—any street will do, but for a good analogy imagine a street built, like Moray Place, in a circle. We can say, speaking of, say, a water plug, or any point in that street, that it is on the center line of the street, or the line of the lamp-posts, or so many feet to one side or either of these lines. There is no visibly marked center line or line of lamp-posts, but it can be filled up in a moment by human intelligence, and if there were to be frequent references to them these lines would be marked on a plan for constant use. The parallels of latitude are similar lines drawn for convenience or reference.

The circumference of the earth, like any other circle, is divisible into 360 degrees, and we number the parallels by the number of degrees of angular divergence; only, instead of beginning at a pole and going right round, we, for convenience sake, begin at the equator and then number 90 degrees towards the North Pole and 90 degrees towards the South Pole.

But one set of reference lines is not enough; we must have another set, and we get them in the *meridians of longitude*. We draw these through the poles at right angles to the equator. They are all "great circles;" that is, each circle is concentric with the globe. The equator being a circle, we divide it as before into 360 degrees, and the meridians through the points of section from a second system of lines of reference. But, unlike the parallels of latitude, they are all the same size. One is the same as another. How are they to be numbered? Go back for a moment to Moray Place, and remember the lines we drew—the center of the street, and the line of the lamp-posts. How are we to define a spot on one of these lines? They are circular, and consequently have no beginning and no end. What we should do would be to mark a convenient spot with a flag, or a peg, or a stone, and say "That is the beginning; measure from that."

This is exactly what we must do in longitude. We must mark a starting line on the earth, and call it zero; and as all nations have a free choice they have not chosen the same. We have chosen the meridian of Greenwich, the French that of Paris, the Americans Washington, and the Russians Pulkova and the Germans used to use Ferro: but for all English maps, and now for most foreign ones, the meridian of Greenwich is the starting line, the zero of longitude.

The custom here again is not to reckon 360 degrees round the circle, but to reckon 180 degrees east and 180 degrees west. We saw that latitude was angular divergence from the equator; but what are these degrees of longitude? Look at a ball spinning round opposite a candle. We assumed a knowledge that the earth spun round its axis in twenty-four hours. Every part of it comes in turn opposite a heavenly body

(say the sun) once in twenty-four hours, just as every part of this ball comes opposite the candle once in each revolution. Longitude is, then, angular divergence measured by the *difference of time* in coming opposite a heavenly body. As the circle is divisible into 360 degrees, so the day, *i. e.*, the revolution of the earth, is divisible into twenty-four hours, and one hour of longitude is consequently equal to 15 degrees. In maps longitude is marked in degrees, while in almanacs the elements given to reckon it are always written in hours, minutes, and seconds.

Remember once more, that these degrees are not lengths measured on the surface, but are the record of angular divergence from the initial meridian. It is all the more necessary to bear this in mind, because the length on the surface of the earth of a degree of longitude varies enormously, being greatest at the equator and nothing at all at the pole, differing thus from degrees of latitude, which, roughly speaking and for the purposes of this paper, may be considered equal.

The idea that latitude and longitude are the measures of angular divergence and not absolute distance in miles or yards may be easily grasped by familiar illustration. If you can imagine two travellers leaving Italy by road, the one over the St. Gothard pass and the other over Mount Cenis, and two other travellers following them by rail at such an interval of time that they are in the railway tunnels at exactly the same moment that the pedestrians attain the summits of the passes; the pedestrians on the mountain and the railway traveller in the tunnel of the St. Gothard pass will be in exactly the same latitude and longitude, and so will the travellers by the Mount Cenis routes. The pedestrians however will be about 60 yards farther apart from each other than the railway travellers. The reason of this of course is that the pedestrians are farther away from the earth's center, but their angular divergence from the equator and the earth's axis are precisely the same, whether they are on the mountain or in the tunnel 5,000 feet below.

Now, having defined latitude and longitude and shown how the lines representing them are drawn, we must see how in practice the surveyor finds the latitude and longitude of a place, and thereby begins his map. The poles, as we saw, are first points to measure from, and the equator the half-way line. It is evident he can not measure directly a line from pole to pole, find out the half and call it the equator, and leave pegs at each parallel in passing. He must look to things outside the earth itself from which to reckon, and he gets such reference points in the heavenly bodies. To his eye these are situated in the great vault of the heavens. He sees them as if on the surface of a hollow globe continually revolving around him, rising in the east till they reach their highest point above him, called the culminating point, then setting in the west. For thousands of years astronomers have studied these bodies, and fixed their apparent positions in the celestial vault; and these positions are recorded with the utmost possible accuracy in a book,

compiled by Government, called the *Nautical Almanac*, and, from the practical information given there, the surveyor finds his position. He may take the sun or he may take the stars, but the positions of the sun being affected by the motion of the earth round it, I propose to take a star to illustrate my next remarks, as its movements are simpler.

The pole of the heavens is the end of the axis of the earth infinitely prolonged. The intersection of the plane of the equator with the celestial vault is called the *equinoctial*, and as the angular divergence on the surface of the earth is measured in degrees from the equator and called latitude, so the angular divergence of a heavenly body from the equinoctial is called its *declination*. As the angular divergence from the meridian of Greenwich was called longitude, so the divergence in time from a starting point in the heavens is called *right ascension*. We had to fix arbitrarily the meridian of Greenwich as a starting line on the earth. We have also to fix equally arbitrarily a starting point in the heavens, and that point may be most simply described as the point in the heavens in which the sun is in spring, when the day and night are equal.

The latitude of any place on the earth's crust is equal to the altitude of the celestial pole. You can see this in a moment if you imagine yourself on the equator and look to the pole, marked, say, by the Pole Star. You will see it on the horizon and of no altitude at all; and at the equator you have no lat tude, or it is called zero; but, as you approach the pole, the Pole Star will gradually appear to rise higher and higher until when you reach the North Pole it will be directly over your head, and consequently at right angles to, or 90 degrees from the horizon, and your latitude is then also 90 degrees. But though the Pole Star is very near the North Pole, it does not actualy coincide with it, and we must find some other way of finding our latitude accurately. We get this by taking the altitude of any known star in various ways. I will explain the simplest method, of which all others are only slight modifications:

(1) Measure the *meridian altitude* of the star—that is, its highest altitude above the horizon.

(2) Deduct that altitude from 90 degrees, which gives its *zenith distance*, or the angular distance from a point exactly over your head.

(3) Add (or substract) the *declination* of the star (found in the *Nautical Almanac*) to the *zenith distance*, and the result is your latitude.

I have here a diagram showing how the latitude of Edinburgh would be found from the bright star Arcturus, which "culminates," or reaches its highest altitude, on our meridian a few minutes before 12 to-night.

I measure first its *altitude*, which I find is 54 degrees. Deducting that from 90 degress gives its *zenith distance* = 36 degrees; to that I add its *declination*, which I find from the almanac is 20 degrees, and the result is 56 degrees = the latitude of Edinburgh.

Longitude is a more difficult matter, and I have no time to go into it anything like fully. You will find a beautiful description of it in

Herschel's Astronomy, the best by far of all popular books on the subject. While latitude is absolute, longitude, being difference in time, is relative, for there is no such thing as absolute time; and noon at any place is merely the moment when the sun culminates on the meridian. If the observer has a clock whose going he can depend on, and he sets it to, and keeps it always at, Greenwich time, he knows from that clock or chronometer what time it is at Greenwich when any star comes to the meridian. If then he can observe any astronomical phenomenon, such as the meridian passage of a star, he has only to observe the difference of the times recorded on the clock set to Greenwich time and on his local clock, and the difference is the longitude in time. This is the principle on which longitudes are taken at sea, where chronometers can be kept undisturbed, but for explorers on land it is more difficult.

The moon, however, is a natural clock, very complicated, but still readable to the initiated.* It is continually moving through the stars, and its angular distance from prominent stars is carefully computed for Greenwich, and recorded in the *Nautical Almanac* for every hour in the year. The observer then finding the moon's position by observation, and recording its local time, can find in the *Nautical Almanac* when it had the same position at Greenwich, and the difference of the times is the measure of the longitude.

In old days, when ships met, the first question was, Who are you? the next, What's your longitude? The invention of the chronometer by Harrison one hundred and twenty years ago has however for sailors at least, vastly simplified the finding of longitude at sea: and I find from inquiry among sailors, that "lunars" are practically a lost art. In illustration, I may state that I find from the *Nautical Almanac* that Arcturus comes to the meridian of Greenwich at 11:37 to night. If I have a clock or chronometer marking true Greenwich time, I shall find that this star will come to our meridian at twelve minutes and forty seconds later: the difference of longitude in time is therefore twelve minutes and forty seconds, which, converted into angular measurement, is 3 degrees $10\frac{1}{2}$ minutes, the longitude (west) of Edinburgh.

Note here that at stations differing only in latitude the same star comes to the meridian at the same *time*, but at different *altitudes*. At stations differing only in longitude it comes to the meridian at the same *altitude*, but at different *times*. The instrument generally used for taking altitudes is the sextant.† At sea, where we have a visible

* The student should read the beautiful explanation of longitude in *Herschel's Astronomy*, section 220 *et seq*.

† In reading this paper the sextant, artificial horizon, theodolite, level, plane table, and other instruments were all shown and their uses described. These descriptions are omitted here, and the student is referred for detailed and illustrated descriptions of these and other instruments to Prof. Rankine's *Manual of Civil Engineering* (Griffin, Bohn & Co.), or Mr. Usill's *Practical Surveying* (Crosby, Lockwood & Son, 1889).

horizon—the line where the sea meets the sky—we measure altitudes from this horizon; but on land we have no true horizon, and then we use, what is more accurate, an *artificial horizon*, which is a cup of mercury in which the heavenly body is reflected. Measure the angle between the real body in the sky and its reflection in the mercury, and half the angle is the true altitude.

Projection.—Having discovered our position on the surface of the globe, we come to the representation of it on a flat sheet or map.

The Latin dictionary tells us that "mappa" is a sheet or napkin. Now, the surface of the globe is curved, and in a map we have only a flat surface to represent it on, and we shall for a short while study how, as it is the basis of all map-drawing. The conventional representation on a flat surface of the curved surface of the earth is called projection, because in its fundamental idea it is a picture of the globe projected or thrown forward from the eye on to a flat sheet; but this idea of it is so confusing to the mind unaccustomed to think out such things that, although it is the invariable way of describing it in all text books, I have preferred to show you three forms of projection without assuming any ideal throwing of the rays on to planes.

The first I show is the modified stereographic or equi-globular projection (Plate XXII), invented by Philip de la Hire about the end of the seventeenth century. A simple way of investigating this projection is to fit an iron ring over the center of the globe, and stretch tightly, from the North Pole to the South, India rubber bands that coincide with the meridians of longitude on the globe, fastening them firmly to the ring at the poles. Similarly stretch India-rubber bands over the parallels of latitude, fastening them to the iron ring and to the meridians where they cross. While the ring is kept on the globe these India-rubber bands show the parallels and the meridians on the sphere. When the ring is lifted off the globe the India-rubber shrinks to a plane and shows exactly the lines of the stereographic projection. This is the projection used in all atlases for the world in hemispheres, for continents, and for large surfaces. It gives, indeed, a notion of rotundity and a general idea of projection, but the central portions are shrunk in, and the edges are distorted.

The next projection to be studied is Mercator's. Mercator was a Fleming who lived in the sixteenth century. He was almost an exact contemporary of John Knox. He was a writer on theology and geography. His real name was Gerard Kremer, which name, meaning merchant, he Latinized, in accordance with the custom of the day, into Mercator.

His invention is very clever. The construction of it is a little complicated, and is generally shirked in text books, but the actual idea is very simple, and I have here designed a piece of apparatus to illustrate exactly what I believe Mercator did when he evolved his system.

Though I have no direct evidence to show how Mercator argued out his system, I have not the least doubt that it was somewhat thus:

Mercator was a globe-maker, and no doubt worked from the globe. He stripped his gores off the globe, forming a map like this (Plate XXI, fig. 1), which was naturally very inconvenient, owing to the hiatuses between the meridians. He was obliged to join the gores along their meridians (Plate XXI, fig. 2). He then found that he had distorted everything, and the distortion increased in the higher latitudes, owing to the gores being further apart towards the top of the map. In order to restore a balance of orientation (or the relative position and direction of places), as he had distorted in longitude, so he had exactly in proportion to distort in latitude, as shown in Plate XXI, fig. 3, a complete Mercator's map of half the Northern Hemisphere, in which you will observe that the parallels are farther and farther apart as the latitude gets higher.

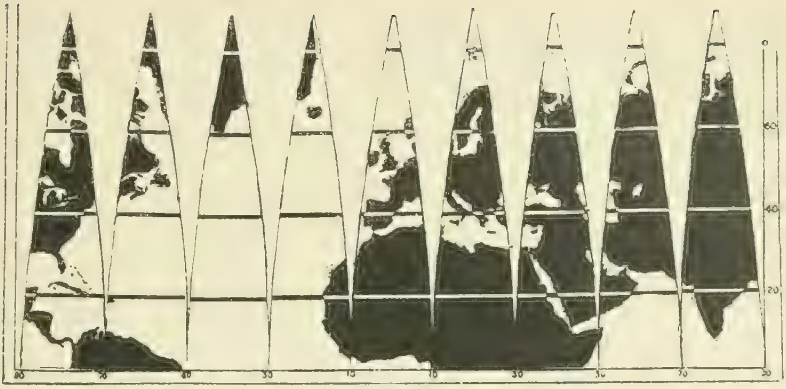
As these gores are not a familiar shape, I have a square here which will catch the eye at once (Plate XXI, fig. 1*a*). I distort it first by pulling it out horizontally as Mercator did in joining the meridians, and it ceases to be a square and the orientation is changed (Plate XXI, fig. 2*a*). I then distort it in height in the same proportion, and it becomes once more a square with the true orientation but larger than the original square (Plate XXI, fig. 3*a*). This is exactly what we did before with the gores of the globe.

Every parallel, in Mercator's projection, is a straight line, and every meridian is also a straight line. We have, then, an excellent sailing line from point to point. As Sir George Grove puts it very neatly (though he shirks the explanation of the projection), "The most ignorant sailor can lay down his course without calculation. In fact, the invention of this map has been justly called one of the most remarkable and useful events of the sixteenth century; because it enables common, unlearned people to do easily and correctly what only clever, learned people could have done without it."

Mercator's projection is that used in all nautical charts to this day, because to the sailor it is far more important to know his direction or course than his distance, which with ordinary nautical knowledge, or from nautical tables made for him, he can easily calculate, but he needs to see his course.

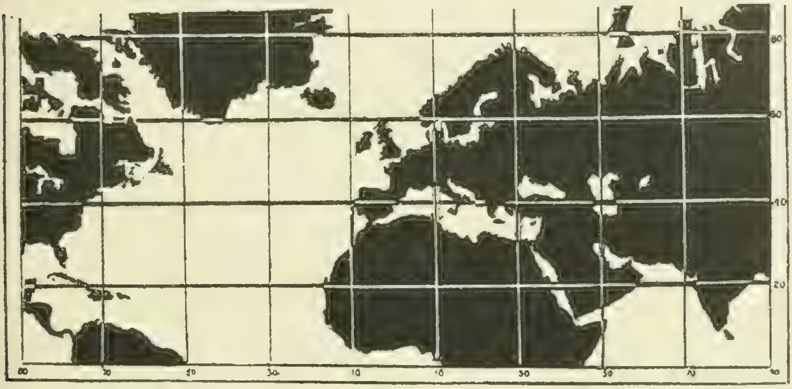
In the conical projection (Plate XXII, fig. 5) we imagine a cone of paper to be rolled round the globe, touching it on the middle line of the map. Near their line of contact the map coincides very nearly with the globe surface, and is fairly accurate; but as it gets farther away from the touching point the distortion grows, the places being shown larger than in reality. For comparatively small areas, such as for maps of England and France, it is fairly accurate, and is the projection used in atlases.

In the illustrations (Plates XXI, XXII) we see the same globe projected

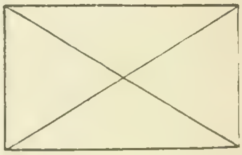


1. Gores from the globe.

1 *a*

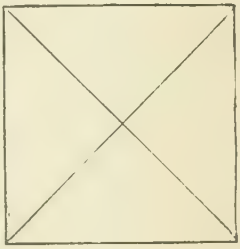


2. The gores stretched out horizontally to meet in straight vertical lines.



2 *a*

3. The map distorted vertically in same proportion as horizontally



3 *a*

MERCATOR'S PROJECTION.

on the same scale, but with very different proportions. These three projections are typical ones and the most commonly used, but there are many others. For those desirous of studying the subject the best work on it I know is the article by Mr. Taylor, in the June number of the *Scottish Geographical Magazine* of 1890, and to that article I refer them.

Map-making.—We have now seen how the traveller finds his place on the globe's surface, and how, when found, he can *project* or map that information on a flat sheet. We shall now see how a map will grow. Imagine a ship sailing into unexplored seas and coming to some land, say an island. The navigator at once fixes his position in the ship in latitude and longtitude. The navigator's instruments are the sextant, the chronometer, and the mariner's compass. The general idea of the mariner's compass is that it always points to the north; but accurately this is not so. The general direction of the compass, or the magnetic pole, is not the true north, but a spot very considerably to the west of it, and, in fact, shifts continually; not only in different places, but even in the same place, the direction changes from time to time, as there are many local causes of disturbance. The navigator, then, to fix true north, must find his meridian—that is, he must observe the direction of a star or the sun when it culminates or comes to the meridian, and from this observation he computes the amount of local variation of the compass. In practice it is not the moment of culmination he actually observes, but the statement is accurate enough for the purpose of this popular description. Knowing the variation of the compass, he can then take accurate bearings or directions to any feature he desires to record. Two or more such bearings to (say) a mountain, crossing each other from different known places, fix its position on the map.

The navigator.—We can now show how a country is mapped. Suppose a ship visits this island, and fixes, by the ways already indicated, a few latitudes and longitudes, and sails round it, fixing here and there points on the coast, and perhaps taking bearings of some mountain, then the island would be represented in an atlas with several points fixed and joined by dotted lines. Nautical surveying is always done with the sextant, which measures both vertical angles and horizontal.

Explorer.—Following in the wake of the sailor comes the explorer. I had intended, when I first sketched out this paper, to give an imaginary explorer's map of a journey across this island, but I have the privilege of showing you something so infinitely precious that I feel it would be a piece of bathos to concoct a sham map. Here I have two of Dr. Livingstone's own original manuscript maps, made on his last journey, kindly lent me for to-night by his daughter, Mrs. A. L. Bruce. Here we have no conjectures as to what the traveller might do; here are the real power, the actual materials of geography. Instead of imagining what an explorer should take with him, I may mention Livingstone's

actual equipment: A 6-inch sextant, an artificial horizon, a pocket chronometer, a prismatic compass, and a pocket compass: two boiling-point thermometers and two common thermometers; aneroid barometer, a *Nautical Almanac*, and a book of mathematical tables.

The sextant, as we have seen, is for taking astronomical as well as terrestrial angles; the thermometer and barometer for taking heights. The principle on which the latter are calculated is the pressure of the atmosphere. The aneroid everybody knows; the boiling-point thermometer is considered better and more accurate, though I observe from Livingstone's notes, who was the most painstaking and thorough observer, and who always observed with both, that there was little practical difference in the readings. Roughly speaking, water boils at sea-level at 212°F., and the barometer stands at 30 inches, while at 5,000 feet altitude water boils at 202·6°, and the barometer falls to 24·7 inches.

The traveller in unexplored parts generally estimates his distances from the time taken at the average rate of marching, just as on board ship distances covered are roughly taken from the average rate of the ship indicated by the log. He takes compass bearings as he goes, and keeps an itinerary, recording all useful information gathered on the march. He corrects his reckoning by taking daily latitudes, and at greater intervals, say once a fortnight, longitudes from moon observations if he can. He notes heights, gets reports from natives of estimated distances, and in fact gathers all the information he can on every subject—rain-fall, botany, zoology, anthropology, and so forth. Livingstone did all these, and did them thoroughly. A whole lecture could be written on these maps I hold in my hand. Here is one of his notes:

"Eight days up this river 96 miles, then cross and go three days, say 36 miles, to stone houses 132 miles—course southwest Lobula, comes to northeast, has dark water."

A traveller with his wits about him can do much with very rough instruments, or even with none at all. He can train himself to use his fingers for rough angular measurements, and he can improvise in many ways. My own old chief, the late Col. W. B. Holmes, R. E., used to make wonderful surveys with his watch alone.

One great geographical problem—where does the huge river Sangpo, which flows in Tibet at the back of the Himalaya, discharge its waters?—was solved by a native surveyor, A. K., sent out by the Government of India, who was obliged to conceal all his observations. I quote from the official account:

"For linear measurement A. K. trusted entirely to his own pace or step, which, as hereafter shown, is convertible into the unit of a foot, or any other unit desired; and notwithstanding that in Mongolia he was looked down upon as a particularly inferior individual, because, unlike the Mongols, he persisted in walking instead of following the universal custom of the country, which enjoins riding a horse on all possible occasions, he yet manfully strode along his travels, pleading poverty, or

4. STEREOGRAPHIC PROJECTION.

5. CONICAL PROJECTION.

otherwise, until at last, on his return journey along the eastern flank of his route, the Lama with whom he had taken service insisted on his riding, if only to promote flight from robbers, especially the mounted bands of Chiámo-Goloks, of whom travellers are in constant dread. Thus compelled, A. K. mounted a horse, but here also he proved equal to the occasion, for he at once set to work counting the beast's paces as indicated by his stepping with the right foreleg. In this way he reckoned his distances for nearly 230 miles, between Bárong Chaidam (latitude 36° 5′, longitude 97° 3′), and Thuden Gomba (latitude 33° 17′, longitude 96° 43′), and the results do credit alike to the explorer's ingenuity and to the horse's equability of pace."

An account of his journey will be found in the *Scottish Geographical Magazine* for 1885, p. 352.

After the explorer comes the *surveyor*. His business is to produce a detailed survey or map of the country. The operations of a cadastral* survey on a grand scale, generally made by the Government, are divided into two parts: (1) the great triangular survey, and (2) the topographical part, or the filling in of the details required for civil information.

Before we go further we should gain a thorough idea of the principles of triangulation, because on it are founded all the conditions of an accurate map. The great property of a triangle is this, that of all plane geometrical figures it is the only one of which the form can not be altered if the sides remain constant, and that the three angles of a triangle are together equal to two right angles, so that if we know two of the angles of any triangle we can at once calculate the third angle by subtracting the number of degrees in the two known angles from 180 degrees, which is the sum of two right angles. If also we know the length of one of the sides of the triangle as well as the number of degrees in the angles, a very simple mathematical formula enables us to calculate the length of the other sides.

Now this is exactly what is done in the great trigonometrical survey made in this country by the Ordnance Survey: The surveyor measures what is called a *base line*. He purposely selects an absolutely horizontal plane otherwise conveniently situated for the purpose of measurement. The base line is seldom more than 5 or 6 miles long, but it is measured with "every refinement which ingenuity can devise or expense command." In the Ordnance Survey of the British Isles—to give an idea of the care with which such base lines are measured—the original base line, which was on Hounslow Heath, was measured in 1791, first with a steel chain, then with deal rods, next glass tubes, and lastly, again with the chain; and was over 5 miles long. Another line was subsequently measured 7 miles long, on Salisbury Plain, in 1794, which is the base of the existing triangulation. The verification line at Lough

*A cadastral survey is properly and etymologically a survey by a government for fiscal purposes, the word being derived from the low Latin *capitastrum*, a register for a poll tax. As such a survey was naturally carried out with the utmost completeness, the term "Cadastral Survey" came to be used equally with the term "Ordnance Survey" for the great Government survey of Great Britain and Ireland.

Foyle, which was 7 miles long, was measured with specially designed compound metal rods of brass and iron, 10 feet long, compensating like the balance and spring of a chronometer, so as to be independent of expansion and contraction, and their contact adjusted with microscopes. From this base once fixed, its latitude and longitude being most carefully taken, the surveyor measures the angles of suitably laid out triangles, and computes the length of their sides. Each of these sides in its turn becomes the base of a new triangle. The surveyor plants his instrument on the spot fixed on and measures new triangles, and gradually covers the surface of his island with a network of great triangles. The length of these sides are all calculated from the angles not measured, but, as a matter of fact, the lengths of these sides so computed from angular measurements are infinitely more accurate than if they were actually measured with a chain.

So accurate, indeed, was the triangulation of this country that when the ordnance surveys verified their calculations thirty-three years after, in 1827, by actually measuring the check base on Lough Foyle, as already described, the greatest possible error was found to be less than 5 inches. This, be it remembered, was calculated from the base in Salisbury Plain, only 7 miles long, at a distance of over 300 miles. The mean length of the sides of the triangles was 35 miles, and the longest side was 111 miles. The history of the triangulation is quite a romance, but Sir Charles Wilson referred to all this at length last month.*

The instrument with which the angles are measured is the theodolite. This network of triangles so laid down is the backbone of all details of map-making. All these imaginary sides of triangles are, like the parallels of latitudes and meridians on large maps, the lines to which all filling in of detail is referred. Every point on this network is absolutely fixed, and from these points, as from the line of lamp-posts we considered at the beginning, all details are measured. The great triangulation in the Ordnance Survey being complete, the officers then lay off from the great triangles what are called secondary triangles, the sides of which are about 5 miles in length, and where necessary, tertiary triangles, with sides of about 1 mile in length, and from them the surveyor breaks up the interior of the triangle with a network of cross lines, all self-checking when laid on the paper, and this is the beginning of ordinary land survey.

Land surveying.—The filling in of a survey is like writing a book. Men work differently. No two surveyors use exactly the same method of working, and it very much depends on the nature of the ground, the extent of his resources, and the accuracy of detail required what method the surveyor employs. In a theoretically perfect survey the triangular system would be pursued throughout, but in practice this is not necessary, nor is it done.

The Scottish Geographical Magazine, vol. VII, p. 248. An admirable popular account of the operations of the Ordnance Survey will be found in *The Ordnance Survey of the United Kingdom,* by Lieut. Col. T. P. White, R. E. (Blackwood, 1886.)

Of the methods of filling up, which are several, I will briefly describe two or three of the principal:

Traversing with the chain and theodolite.—A traverse is defined as a circuitous route performed on leaving any place on the earth's surface by stages in different directions and of various lengths with a view of arriving at any other place. The angles which the stages (or station lines) form with the meridian (*i. e.*, the north and south line) are called bearings. In other words, it is a walking from point to point in straight lines, always recording your distance and your direction.

These traverse lines are measured with the chain. They are generally laid out round the country to be surveyed, and are as multifarious as the necessities of the ground require. The bearings in a good permanent survey are measured with the theodolite, and when the traverse is complete it should be closed where begun, when, if no error is made, the bearing of the first line will read on the theodolite exactly as it read in the beginning. Cross checks and connecting lines are constantly taken to test the accuracy of the work, and while the survey is going on the measurements of all the features of the country are set down in what is called the field book. Where the line does not cross the natural features perpendiculars, called offsets, are set off and measured from the traverse line to the bends and angles of all surface details, bends of streams, fences, houses, roads, and so on, and so the map gets filled in bit by bit. Either it is set off at the beginning from the ordnance triangulation or subsequently joined to it by trigonometrical measurements. Such detail may be made piecemeal and fitted in like a Chinese puzzle to the main map of the country and altered or more minutely surveyed, according to requirements. For rapid and not very accurate purposes exactly the same methods may be adopted as for a military reconnoissance or sketch map by pacing the traverse lines and taking the bearings with the prismatic compass, and this is what is generally done in military sketches. All these operations and measurements are noted in a field book and are afterwards taken to the office and "plotted" on a sheet or sheets of paper.

There is also a contrivance for filling in a survey, with which no field book is used, but by which very fairly accurate work may be obtained. It is very little used in this country except for military purposes, and then generally in a modified form shortly to be noticed; but it is much used for topographical work in India and on the continent and the United States. This instrument is the *plane table*. It serves itself as a theodolite, and the plan actually grows on the ground without after office work.

Contour lines.—A very important part of cadastral survey is the plotting on the map of contour lines, or lines of equal height. This is done after the features of the surface have been mapped. To draw the contour lines we must have a starting point, or, as it is called, a datum level. In our Ordnance Survey this is the level of the mean tide at Liverpool.

From the datum great lines and cross lines of levels are run all over the country, covering it with a network; and at all convenient spots the heights are permanently recorded by the well-known broad arrow, and called bench marks. Wherever the broad arrow is found engraved on the ground its height from the datum line will be found in the ordnance map of that part of the ground. A very common spot to find an ordnance bench mark is the keystone of the arch of a bridge, which would naturally be the last thing to be removed. These levels are got by spirit levelling. When the main levelling operations have been completed the surveyor fixes at what intervals of height his contours are to be drawn.

The surveyor starts, let us say, to determine the line at 100 feet above datum. He goes to the nearest bench mark he has to this height, say it is 105 feet. He levels down until he finds a point 5 feet below this bench mark. There he leaves a flag or a peg and goes on finding point after point at the same level; that is, he must read the same figure on the leveling staff. These points he then surveys as he would any natural feature, and permanently marks the imaginary lines joining them on the map, thereby showing a line of equal heights.

Military sketch or *reconnoissance* is a form of map which ought not to pass entirely undescribed. The object of a staff officer in making a sketch is to give such a representation of the nature of the ground as will give useful information to his general. It may take any amount of elaboration, may be as complete as a cadastral survey taken with instruments of precision, or it may be merely the roughest indication of the nature of the ground, taken with such instruments as may be carried in the pocket, or even improvised without instruments, and be a mere eye sketch of the features of the ground. As the military information generally desired is the nature of the ground, whether suitable for maneuvering, for artillery, for cavalry, the nature of the roads, of the hills, of the rivers, should all be looked to, and rough contouring and hill shading is a very important part of the officer's work. He must also get information of defensible spots, of the water supplies, the food supplies, and the resources of the country, and this should be modified as much as possible on the plan or on the report attached to it.

Though any degree of elaborateness may be used, any instruments of precision employed, the typical military sketch is made with a sketching case, which is merely an improvised plane table. The main lines or traverses are taken from the bearings of the prismatic compass laid down on the sketch itself. The lines are generally paced or guessed, distant objects fixed by bearings from the station points, and the contouring measured angularly by Abney's level, or sketch by the eye. The shading of the hills shows steepness by the lines used to indicate them being drawn closer or farther apart.

Cartographer.—The plans and maps having been drawn, and all notes made of information, they reach the cartographer or atlas-maker. His duty is first to compare all new information with what is already

known; to eliminate manifest errors, to reduce to scale and to projection uniform with his great maps of the same part of the world, and generally to make everything ship-shape for publication.

Atlas-making.—I do not here refer to the Ordnance Survey maps, drawings, and prints, which were described with the utmost detail and precision by Sir Charles Wilson, but to the general atlases, such as Johnston's and Bartholomew's. With the information so gleaned the cartographer is able to make those beautiful orographical maps, which are now so common, showing different levels.

In our diagram I have colored the island orographically, which is done by drawing the contour lines and washing over the areas so marked with different variations of tint. But I shall not go far into this subject. Imagine the map drawn. It may be then engraved, like any other picture or line engraving, on a copper plate, and either printed from that plate or from lithographic stones, to which an impression of the plate has been transferred.

In the Ordnance Survey printing office, instead of lithographic stone, the maps are printed from sheets of zinc, which has much the same property of absorbing greasy ink.

By this time we have got into the printing office, and to describe it in detail would be beyond my province. This part of the subject though very interesting, really embraces the whole art of the engraver, the lithographer, and the printer. But there is one process I desire to show before closing.

You see daily in books and newspapers, and in our own journal, maps printed in black along with the type. There are numberless processes for their production; one only I shall briefly note. It is in the type process of Messrs. Walker & Boutall, who have kindly sent me a specimen in course of manufacture.

On a brass plate a coating of a waxy composition is laid; the outlines of the map are either drawn on this coating or photographically transferred to it. The engraver then scratches through the wax down to the brass with a needle. He next takes suitable types and stamps in the names also down through the wax to the brass, and completes the matrix with the necessary amount of detail, which may be great or little. After verification and correction the matrix is ready for electrotyping. You who know the appearance of stereotype molds will see that this resembles the mold of an ordinary stereotype or electrotype page. The mold is next covered with black lead and an electrotype taken from it, when all the punctures that have been made through the wax to the level brass plate come out level—the scratches as lines and the type as lettering. It is then mounted on wood, and is ready to insert among type and be printed along with it.

I have tried to give you very roughly an outline of how maps are made from the beginning to the end, in almost the same form that actual necessity forced me to learn it for practical use.

BIOLOGY IN RELATION TO OTHER NATURAL SCIENCES.*

By J. S. BURDON-SANDERSON, F. R. S.

We are assembled this evening as representatives of the sciences—men and women who seek to advance knowledge by scientific methods. The common ground on which we stand is that of belief in the paramount value of the end for which we are striving, of its inherent power to make men wiser, happier, and better; and our common purpose is to strengthen and encourage one another in our efforts for its attainment. We have come to learn what progress has been made in departments of knowledge which lie outside of our own special scientific interests and occupations, to widen our views, and to correct whatever misconceptions may have arisen from the necessity which limits each of us to his own field of study; and, above all, we are here for the purpose of bringing our divided energies into effectual and combined action.

Probably few of the members of the association are fully aware of the influence which it has exercised during the last half century and more in furthering the scientific development of this country. Wide as is the range of its activity, there has been no great question in the field of scientific inquiry which it has failed to discuss; no important line of investigation which it has not promoted; no great discovery which it has not welcomed. After more than sixty years of existence it still finds itself in the energy of middle life, looking back with satisfaction to what it has accomplished in its youth, and forward to an even more efficient future. One of the first of the national associations which exist in different countries for the advancement of science, its influence has been more felt than that of its successors, because it is more wanted. The wealthiest country in the world, which has profited more, vastly more, by science than any other, England stands alone in the discredit of refusing the necessary expenditure for its development, and cares not that other nations should reap the harvest for which her own sons have labored.

It is surely our duty not to rest satisfied with the reflection that England in the past has accomplished so much, but rather to unite

*Inaugural Presidential address before British Association, for the Advancement of Science; at Notingham, September 13, 1893. (*Nature*, Sept. 14, 1893; vol. XLVIII, pp. 464–472.)

and agitate in the confidence of eventual success. It is not the fault of governments, but of the nation, that the claims of science are not recognized. We have against us an overwhelming majority of the community, not merely of the ignorant, but of those who regard themselves as educated, who value science only in so far as it can be turned into money; for we are still in great measure, in greater measure than any other, a nation of shop-keepers. Let us who are of the minority—the remnant who believe that truth is in itself of supreme value, and the knowledge of it of supreme utility—do all that we can to bring public opinion to our side, so that the century which has given Young, Faraday, Lyell, Darwin, Maxwell, and Thompson to England may, before it closes, see us prepared to take our part with other countries in combined action for the full development of natural knowledge.

Last year the necessity of an imperial observatory for physical science was, as no doubt many are aware, the subject of a discussion in Section A, which derived its interest from the number of leading physicists who took part in it, and especially from the presence and active participation of the distinguished man who is at the head of the National Physical Laboratory at Berlin. The equally pressing necessity for a central institution for chemistry, on a scale commensurate with the practical importance of that science, has been insisted upon in this association and elsewhere by distinguished chemists. As regards biology, I shall have a word to say in the same direction this evening. Of these three requirements it may be that the first is the most pressing. If so, let us all, whatever branch of science we represent, unite our efforts to realize it, in the assurance that if once the claim of science to liberal public support is admitted the rest will follow.

In selecting a subject on which to address you this evening, I have followed the example of my predecessors in limiting myself to matters more or less connected with my own scientific occupations, believing that in discussing what most interests myself I should have the best chance of interesting you. The circumstance that at the last meeting of the British Association in this town, Section D assumed for the first time the title which it has since held, that of the Section of Biology, suggested to me that I might take the word "biology" as my starting point, giving you some account of its origin and first use, and of the relations which subsist between biology and other branches of natural science.

ORIGIN AND MEANING OF THE TERM "BIOLOGY."

The term "biology," which is now so familiar as comprising the sum of the knowledge which has as yet been acquired concerning living nature, was unknown until after the beginning of the present century. The term was first employed by Treviranus, who proposed to himself as a life-task the development of a new science, the aim of which should

be to study the forms and phenomena of life, its origin, and the conditions and laws of its existence, and embodied what was known on these subjects in a book of seven volumes, which he entitled *Biology, or the Philosophy of Living Nature.* For its construction the material was very scanty, and was chiefly derived from the anatomists and physiologists. For botanists were entirely occupied in completing the work which Linnaeus had begun, and the scope of zoology was in like manner limited to the description and classification of animals. It was a new thing to regard the study of living nature as a science by itself, worthy to occupy a place by the side of natural philosophy, and it was therefore necessary to vindicate its claim to such a position. Treviranus declined to found this claim on its useful applications to the arts of agriculture and medicine, considering that to regard any subject of study in relation to our bodily wants—in other words, to utility—was to narrow it, but dwelt rather on its value as a discipline and on its surpassing interest. He commends biology to his readers as a study which, above all others, "nourishes and maintains the taste for simplicity and nobleness; which affords to the intellect ever new material for reflection, and to the imagination an inexhaustible source of attractive images."

Being himself a mathematician as well as a naturalist, he approaches the subject both from the side of natural philosophy and from that of natural history, and desires to found the new science on the fundamental distinction between living and non-living materials. In discussing this distinction, he takes as his point of departure the constancy with which the activities which manifest themselves in the universe are balanced, emphasizing the impossibility of excluding from that balance the vital activities of plants and animals. The difference between vital and physical processes he accordingly finds, not in the nature of the processes themselves, but in their co-ordination; that is, in their adaptedness to a given purpose, and to the peculiar and special relation in which the organism stands to the external world. All of this is expressed in a proposition difficult to translate into English, in which he defines life as consisting in the reaction of the organism to external influences, and contrasts the uniformity of vital reactions with the variety of their exciting causes.*

The purpose which I have in view in taking you back as I have done to the begining of the century is not merely to commemorate the work done by the wonderfully acute writer to whom we owe the first scientific conception of the science of life as a whole, but to show that this conception, as expressed in the definition I have given you as its foundation, can still be accepted as true. It suggests the *idea of organism* as that to which all other biological ideas must relate. It also suggests,

*"Leben besteht in der Gleichförmigkeit der Reaktionen bei ungleichförmigen Einwirkungen der Aussenwelt."—Treviranus, *Biologie oder Philosophie der lebenden Natur*, Göttengen, 1802, vol. I, p. 83.

although perhaps it does not express it, that *action* is not an attribute to the organism but of its essence—that if, on the other hand, protoplasm is the basis of life, life is the basis of protoplasm. Their relations to each other are reciprocal. We think of the visible structure only in connection with the invisible process. The definition is also of value as indicating at once the two lines of inquiry into which the science has divided by the natural evolution of knowledge. These two lines may be easily educed from the general principle from which Treviranus started, according to which it is the fundamental characteristic of the organism that all that goes on in it is to the advantage of the whole. I need scarcely say that this fundamental conception of organism has at all times presented itself to the minds of those who have sought to understand the distinction between living and non-living. Without going back to the true father and founder of biology, Aristotle, we may recall with interest the language employed in relation to it by the physiologists of three hundred years ago. It was at that time expressed by the term *consensus partium*—which was defined as the concurrence of parts in action, of such a nature that each does *quod suum est*, all combining to bring about one effect "as if they had been in secret council," but at the same time *constanti quadam naturæ lege*.* Prof. Huxley has made familiar to us how a century later Descartes imagined to himself a mechanism to carry out this *consensus*, based on such scanty knowledge as was then available of the structure of the nervous system. The discoveries of the early part of the present century relating to the reflex action and the functions of sensory and motor nerves, served to realize in a wonderful way his anticipations as to the channels of influence, afferent and efferent, by which the *consensus* is maintained; and in recent times (as we hope to learn from Prof. Horsley's lecture on the physiology of the nervous system) these channels have been investigated with extraordinary minuteness and success.

Whether with the old writers we speak about *consensus*, with Treviranus about *adaptation*, or are content to take *organism* as our point of departure, it means that, regarding a plant or an animal as an organism, we concern ourselves primarily with its activities, or, to use the word which best expresses it, its energies. Now the first thing that strikes us in beginning to think about the activities of an organism is that they are naturally distinguishable into two kinds, according as we consider the action of the whole organism in its relation to the external world or to other organisms, or the action of the parts or organs in their relation to each other. The distinction to which we are thus led between the *internal* and *external* relations of plants and animals has of course always existed, but has only lately come into such prominence that it divides biologists more or less completely into two camps—on

* Bausner, *De Consensu Partium Humani Corporis*, Amst., 1556, Præf. ad lectorem, p. 4.

the one hand those who make it their aim to investigate the actions of the organism and its parts by the accepted methods of physics and chemistry, carrying this investigation as far as the conditions under which each process manifests itself will permit; on the other, those who interest themselves rather in considering the place which each organism occupies, and the part which it plays in the economy of nature. It is apparent that the two lines of inquiry, although they equally relate to what the organism *does*, rather than to what it *is*, and therefore both have equal right to be included in the one great science of life, or biology, yet lead in directions which are scarcely even parallel. So marked, indeed, is the distinction. that Prof. Haeckel some twenty years ago proposed to separate the study of organisms with reference to their place in nature under the designation of "œcology," defining it as comprising "the relations of the animal to its organic as well as to its inorganic environment, particularly its friendly or hostile relations to those animals or plants with which it comes into direct contact."* Whether this term expresses it or not, the distinction is a fundamental one. Whether with the œcologist we regard the organism in relation to the world, or with the physiologist as a wonderful complex of vital energies, the two branches have this in common, that both studies fix their attention, not on stuffed animals, butterflies in cases, or even microscopical sections of the animal or plant body—all of which relate to the framework of life—but on life itself.

The conception of biology which was developed by Treviranus as far as the knowledge of plants and animals which then existed rendered possible, seems to me still to express the scope of the science. I should have liked, had it been within my power, to present to you both aspects of the subject in equal fulness; but I feel that I shall best profit by the present opportunity if I derive my illustrations chiefly from the division of biology to which I am attached—that which concerns the *internal* relations of the organism, it being my object not to specialize in either direction, but as Treviranus desired to do, to regard it as part—surely a very important part—of the great science of nature.

The origin of life, the first transition from non-living to living, is a riddle which lies outside of our scope. No seriously-minded person however doubts that organized nature as it now presents itself to us has become what it is by a process of gradual perfecting or advancement, brought about by the elimination of those organisms which failed to obey the fundamental principle of adaptation which Treviranus indicated. Each step therefore in this evolution is a reaction to external influences, the motive of which is essentially the same as that by which

*These he identifies with "those complicated mutual relations which Darwin designates as conditions of the struggle for existence." Along with chorology—the distribution of animals—œcology constitutes what he calls *Relations-physiologie*. Haeckel, "Entwickelungsgang u. Aufgaben der Zoologie," *Jenaische Zeitschr.* 1869, vol. v, p. 353.

from moment to moment the organism governs itself. And the whole process is a necessary outcome of the fact that those organisms are most prosperous which look best after their own welfare. As in that part of biology which deals with the internal relations of the organism, the interest of the individual is in like manner the sole motive by which every energy is guided. We may take what Treviranus called *selfish* adaptation—*Zweckmässigkeit für sich selber*—as a connecting link between the two branches of biological study. Out of this relation springs another which I need not say was not recognized until after the Darwinian epoch—that, I mean, which subsists between the two evolutions, that of the race and that of the individual. Treviranus, no less distinctly than his great contemporary Lamarck, was well aware that the affinities of plants and animals must be estimated according to their developmental value, and consequently that classification must be founded on development; but it occurred to no one what the real link was between descent and development; nor was it indeed until several years after the publication of the "Origin" that Haeckel enunciated that "biogenetic law," according to which the development of any individual organism is but a memory, a recapitulation by the individual of the development of the race—of the process for which Fritz Müller had coined the excellent word "phylogenesis;" and that each stage of the former is but a transitory re-appearance of a bygone epoch in its ancestral history. If therefore we are right in regarding ontogenesis as dependent on phylogenesis, the origin of the former must correspond with that of the latter; that is, on the power which the race or the organism at every stage of its existence possesses of profiting by every condition or circumstance for its own advancement.

From the short summary of the connection between different parts of our science you will see that biology naturally falls into three divisions, and these are even more sharply distinguished by their methods than by their subjects, namely, *physiology*, of which the methods are entirely experimental; *morphology*, the science which deals with the forms and structure of plants and animals, and of which it may be said that the body is anatomy, the soul, development; and finally, *œcology*, which uses all the knowledge it can obtain from the other two, but chiefly rests on the exploration of the endless varied phenomena of animal and plant life as they manifest themselves under natural conditions. This last branch of biology—the science which concerns itself with the external relations of plants and animals to each other, and to the past and present conditions of their existence—is by far the most attractive. In it those qualities of mind which especially distinguish the naturalist find their highest exercise, and it represents more than any other branch of the subject what Treviranus termed the "philosophy of living nature." Notwithstanding the very general interest which several of its problems excite at the present moment I do not propose to discuss any of them, but rather to limit myself to the humbler task of showing that the fun-

damental idea which finds one form of expression in the world of living beings regarded as a whole—the prevalence of the best—manifests itself with equal distinctness, and plays an equally essential part in the internal relations of the organism in the great science which treats of them—physiology.

ORIGIN AND SCOPE OF MODERN PHYSIOLOGY.

Just as there was no true philosophy of living nature until Darwin, we may with almost equal truth say that physiology did not exist as a science before Johannes Müller. For although the sum of his numerous achievements in comparative anatomy and physiology, notwithstanding their extraordinary number and importance, could not be compared for merit and fruitfulness with the one discovery which furnished the key to so many riddles, he, no less than Darwin, by his influence on his successors, was the beginner of a new era.

Müller taught in Berlin from 1833 to 1857. During that time a gradual change was in progress in the way in which biologists regarded the fundamental problem of life. Müller himself, in common with Treviranus and all the biological teachers of his time, was a vitalist, *i. e.* he regarded what was then called the *vis vitalis*—the *Lebenskraft*—as something capable of being correlated with the physical forces; and as a necessary consequence held that phenomena should be classified or distinguished, according to the forces which produced them, as vital or physical, and that all those processes—that is, groups or series of phenomena in living organisms—for which, in the then very imperfect knowledge which existed, no obvious physical explanation could be found, were sufficiently explained when they were stated to be dependent on so-called vital laws. But during the period of Müller's greatest activity times were changing, and he was changing with them. During his long career as professor at Berlin he became more and more objective in his tendencies, and exercised an influence in the same direction on the men of the next generation, teaching them that it was better and more useful to observe than to philosophize; so that, although he himself is truly regarded as the last of the vitalists—for he was a vitalist to the last—his successors were adherents of what has been very inadequately designated the mechanistic view of the phenomena of life. The change thus brought about just before the middle of this century was a revolution. It was not a substitution of one point of view for another, but simply a frank abandonment of theory for fact, of speculation for experiment. Physiologists ceased to theorize because they found something better to do. May I try to give you a sketch of this era of progress?

Great discoveries as to the structure of plants and animals had been made in the course of the previous decade, those especially which had resulted from the introduction of the microscope as an instrument of research. By its aid Schwann had been able to show that all organ-

ized structures are built up of those particles of living substance which we now call cells, and recognize as the seats and sources of every kind of vital activity. Hugo Mohl, working in another direction, had given the name "protoplasm" to a certain hyaline substance which forms the lining of the cells of plants, though no one as yet knew that it was the essential constituent of all living structures—the basis of life no less in animals than in plants. And, finally, a new branch of study, histology, founded on observations which the microscope had for the first time rendered possible, had come into existence. Bowman, one of the earliest and most successful cultivators of this new science, called it physiological anatomy,* and justified the title by the very important inferences as to the secreting function of epithelial cells and as to the nature of muscular contraction, which he deduced from his admirable anatomical researches. From structure to function, from microscopical observation to physiological experiment, the transition was natural. Anatomy was able to answer some questions, but asked many more. Fifty years ago physiologists had microscopes but had no laboratories. English physiologists, Bowman, Paget, Sharpey, were at the same time anatomists, and in Berlin, Johannes Müller, along with anatomy and physiology, taught comparative anatomy and pathology. But soon that specialization which, however much we may regret its necessity, is an essential concomitant of progress, became more and more inevitable. The structural conditions on which the processes of life depend had become, if not known, at least accessible to investigation; but very little indeed had been ascertained of the nature of the processes themselves, so little indeed, that if at this moment we could blot from the records of physiology the whole of the information which had been acquired, say in 1840, the loss would be difficult to trace, not that the previously-known facts were of little value, but because every fact of moment has since been subjected to experimental verification. It is for this reason that, without any hesitation, we accord to Müller and to his successors, Brücke, du Bois-Reymond, Helmholtz, who were his pupils, and Ludwig, in Germany, and to Claude Bernard † in France, the title of founders of our science. For it is the work which they began at that remarkable time (1845–1855), and which is now being carried on by their pupils or their pupils' pupils in England, America, France, Germany, Denmark, Sweden, Italy, and even in that youngest contributor to the advancement of science, Japan, that physiology has been gradually built up to whatever completeness it has at present attained.

What were the conditions that brought about this great advance which coincided with the middle of the century? There is but little

* The first part of the *Physiological Anatomy* appeared in 1843. It was concluded in 1856.

† It is worthy of note that these five distinguished men were merely contemporaries; Ludwig graduated in 1839; Bernard in 1843; the other three between those dates. Three survive—Helmholtz, Ludwig, du Bois-Reymond.

difficulty in answering the question. I have already said that the change was not one of doctrine, but of method. There was however a leading idea in the minds of those who were chiefly concerned in bringing it about. That leading notion was that however complicated may be the conditions under which vital energies manifest themselves, they can be split into processes which are identical in nature with those of the non-living world, and, as a corollary to this, that the analyzing of a vital process into its physical and chemical constituents, so as to bring these constituents into measurable relation with physical or chemical standards, is the only mode of investigating them which can lead to satisfactory results.

There were several circumstances which at that time tended to make the younger physiologists (and all of the men to whom I have just referred were then young) sanguine—perhaps too sanguine, in the hope that the application of experimental methods derived from the exact sciences would afford solutions of many physiological problems. One of these was the progress which had been made in the science of chemistry, and particularly the discovery that many of the compounds which before had been regarded as special products of vital processes, could be produced in the laboratory, and the more complete knowledge which had been thereby acquired of their chemical constitutions and relations. In like manner the new school profited by the advances which had been made in physics, partly by borrowing from the physical laboratory various improved methods of observing the phenomena of living beings, but chiefly in consequence of the direct bearing of the crowning discovery of that epoch (that of the conservation of energy) on the discussions which then took place as to the relations between vital and physical forces; in connection with which it may be noted that two of those who (along with Mr. Joule and your president at the last Nottingham meeting) took a prominent part in that discovery—Helmholtz and J. R. Mayer—were physiologists as much as they were physicists. I will not attempt even to enumerate the achievements of that epoch of progress. I may however without risk of wearying you, indicate the lines along which research at first proceeded, and draw your attention to the contrast between then and now. At present a young observer who is zealous to engage in research finds himself provided with the most elaborate means of investigation, the chief obstacle to his success being that the problems which have been left over by his predecessors are of extreme difficulty, all of the easier questions having been worked out. There were then also difficulties, but of an entirely different kind. The work to be done was in itself easier, but the means for doing it were wanting, and every investigator had to depend on his own resources. Consequently the successful men were those who, in addition to scientific training, possessed the ingenuity to devise and the skill to carry out methods for themselves. The work by which du Bois-Reymond laid the foundation of animal electricity would

not have been possible had not its author, besides being a trained physicist, known how to do as good work in a small room in the upper floor of the old university building at Berlin as any which is now done in his splendid laboratory. Had Ludwig not possessed mechanical aptitude, in addition to scientific knowledge, he would have been unable to devise the apparatus by which he measured and recorded the variations of arterial pressure (1848), and verified the principles which Young had laid down thirty years before as to the mechanics of the circulation. Nor, lastly, could Helmholtz, had he not been a great deal more than a mere physiologist, have made those measurements of the time relations of muscular and nervous responses to stimulation, which not only afford a solid foundation for all that has been done since in the same direction, but has served as models of physiological experiment, and as evidence that perfect work was possible and was done by capable men, even when there were no physiological laboratories.

Each of these examples relates to work done within a year or two of the middle of the century.* If it were possible to enter more fully on the scientific history of the time, we should, I think, find the clearest evidence, first, that the foundation was laid in anatomical discoveries, in which it is gratifying to remember that English anatomists (Allen, Thomson, Bowman, Goodsir, Sharpey) took considerable share; secondly, that progress was rendered possible by the rapid advances which, during the previous decade, had been made in physics and chemistry, and the participation of physiology in the general awakening of the scientific spirit which these discoveries produced. I venture however to think that notwithstanding the operation of these two causes, or rather combinations of causes, the development of our science would have been delayed had it not been for the exceptional endowments of the four or five young experimenters whose names I have mentioned, each of whom was capable of becoming a master in his own branch, and of guiding the future progress of inquiry.

Just as the affinities of an organism can be best learned from its development, so the scope of a science may be most easily judged of by the tendencies which it exhibits in its origin. I wish now to complete the sketch I have endeavored to give of the way in which physiology entered on the career it has since followed for the last half century, by a few words as to the influence exercised on general physiological theory by the progress of research. We have seen that no real advance was made until it became possible to investigate the phenomena of life by methods which approached more or less closely to those of the physicist, in exactitude. The methods of investigation

* The "Untersuchungen über thierische Electricität" appeared in 1848; Ludwig's researches on the circulation, which included the first description of the "kymograph" and served as the foundation of the "graphic method" in 1847; Helmholtz's research on the propagation in motor nerves in 1851.

being physical or chemical, the organism itself naturally came to be considered as a complex of such processes, and nothing more. And in particular the idea of adaptation, which, as I have endeavored to show, is not a consequence of organism, but its essence, was in great measure lost sight of. Not, I think, because it was any more possible than before to conceive of the organism otherwise than as a working together of parts for the good of the whole, but rather that, if I may so express it, the minds of men were so occupied with new facts that they had not time to elaborate theories. The old meaning of the term "adaptation" as the equivalent of "design" had been abandoned, and no new meaning had yet been given to it, and consequently the word "mechanism" came to be employed as the equivalent of "process," as if the constant concomitance or sequence of two events was in itself a sufficient reason for assuming a mechanical relation between them. As in daily life so also in science, the misuse of words leads to misconceptions. To assert that the link between *a* and *b* is mechanical, for no better reason than that *b* always follows *a*, is an error of statement, which is apt to lead the incautious reader or hearer to imagine that the relation between *a* and *b* is understood, when in fact its nature may be wholly unknown. Whether or not at the time which we are considering some physiological writers showed a tendency to commit this error, I do not think that it found expression in any generally accepted theory of life. It may however be admitted that the rapid progress of experimental investigation led to too confident anticipations, and that to some enthusiastic minds it appeared as if we were approaching within measurable distance of the end of knowledge. Such a tendency is, I think, a natural result of every signal advance. In an eloquent Harveian oration, delivered last autumn by Dr. Bridges, it was indicated how, after Harvey's great discovery of the circulation, men were too apt to found upon it explanations of all phenomena whether of health or disease, to such an extent that the practice of medicine was even prejudicially affected by it. In respect of its scientific importance the epoch we are considering may well be compared with that of Harvey, and may have been followed by an undue preference of the new as compared with the old, but no more permanent unfavorable results have shown themselves. As regards the science of medicine, we need only remember that it was during the years between 1845 and 1860, that Virchow made those researches by which he brought the processes of disease into immediate relation with the normal processes of cell development and growth, and so, by making pathology a part of physiology, secured its subsequent progress and its influence on practical medicine. Similarly in physiology, the achievement of those years led on without any interruption or drawback to those of the following generation; while in general biology the revolution in the mode of regarding the internal processes of the animal or plant organism which resulted from these achievements, prepared the way for the acceptance of the still greater

revolution which the Darwinian epoch brought about in the views entertained by naturalists of the relations of plants and animals to each other and to their surroundings.

It has been said that every science of observation begins by going out botanizing, by which, I suppose, is meant that collecting and recording observations is the first thing to be done in entering on a new field of inquiry. The remark would scarcely be true of physiology, even at the earliest stage of its development, for the most elementary of its facts could scarcely be picked up as one gathers flowers in a wood. Each of the processes which go to make up the complex of life requires separate investigation, and in each case the investigation must consist in first splitting up the process into its constituent phenomena, and then determining their relation to each other, to the process of which they form part, and to the conditions under which they manifest themselves. It will, I think, be found that even in the simplest inquiry into the nature of vital processes some such order as this is followed. Thus, for example, if muscular contraction be the subject on which we seek information, it is obvious that, in order to measure its duration, the mechanical work it accomplishes, the heat wasted in doing it, the electro-motive forces which it develops, and the changes of form associated with these phenomena, special modes of observation must be used for each of them, that each measurement must be in the first instance separately made, under special conditions, and by methods specially adapted to the required purpose. In the synthetic part of the inquiry the guidance of experiment must again be sought for the purpose of discriminating between apparent and real causes, and of determining the order in which the phenomena occur. Even the simplest experimental investigations of vital processes are beset with difficulties. For, in addition to the extreme complexity of the phenomena to be examined and the uncertainties which arise from the relative inconstancy of the conditions of all that goes on in the living organism, there is this additional drawback, that, whereas in the exact sciences experiment is guided by well-ascertained laws, here the only principle of universal application is that of adaptation, and that even this can not, like a law of physics, be taken as a basis for deductions, but only as a summary expression of that relation between external exciting causes and the reactions to which they give rise, which, in accordance with Treviranus' definition, is the essential character of vital activity.

THE SPECIFIC ENERGIES OF THE ORGANISM.

When, in 1826, J. Müller was engaged in investigating the physiology of vision and hearing, he introduced into the discussion a term, "specific energy," the use of which by Helmholtz* in his physiological writ-

* "Handb. der physiologischen Optik," 1886, p. 233. Helmholtz uses the word in the plural, the "energies of the nerves of special sense."

ings has rendered it familiar to all students. Both writers mean by the word energy, not the "capacity of doing work," but simply *activity*, using it in its old-fashioned meaning, that of the Greek word from which it is derived. With the qualification "specific," it serves, perhaps, better than any other expression to indicate the way in which adaptation manifests itself. In this more extended sense the "specific energy" of a part or organ—whether that part be a secreting cell, a motor cell of the brain or spinal cord, or one of the photogenous cells which produce the light of the glowworm, or the protoplasmic plate which generates the discharge of the torpedo—is simply the special action which it *normally* performs, its norma or rule of action being in each instance the *interest of the organism* as a whole of which it forms part, and the exciting cause some influence outside of the excited structure, technically called a stimulus. It thus stands for a characteristic of living structures which seems to be universal. The apparent exceptions are to be found in those bodily activities which, following Bichat, we call vegetative, because they go on, so to speak, as a matter of course; but the more closely we look into them the more does it appear that they form no exception to the general rule, that every link in the chain of living action, however uniform that action may be, is a response to an antecedent influence. Nor can it well be doubted that, as every living cell or tissue is called upon to act in the interest of the whole, the organism must be capable of influencing every part so as to regulate its action. For, although there are some instances in which the channels of this influence are as yet unknown, the tendency of recent investigations has been to diminish the number of such instances. In general there is no difficulty in determining both the nature of the central influence exercised and the relation between it and the normal function. It may help to illustrate this relation to refer to the expressive word *Auslösung*, by which it has for many years been designated by German writers. This word stands for the performance of function by the "letting off" of "specific energies." Carrying out the notion of "letting off" as expressing the link between action and reaction, we might compare the whole process to the mode of working to a repeating clock (or other similar mechanism), in which case the pressure of the finger on the button would represent the external influence or stimulus, the striking of the clock, the normal reaction. And now may I ask you to consider in detail one or two illustrations of physiological reaction—of the *letting off of specific energy?*

The repeater may serve as a good example, inasmuch as it is, in biological language, a highly differentiated structure, to which a single function is assigned. So also in the living organism, we find the best examples of specific energy where Müller found them, namely, in the most differentiated, or, as we are apt to call them, the *highest* structures. The retina, with the part of the brain which belongs to it, together constitute such a structure, and will afford us therefore the illustration we

want, with this advantage for our present purpose, that the phenomena are such as we all have it in our power to observe in ourselves. In the visual apparatus the principle of *normality* of reaction is fully exemplified. In the physical sense the word "light" stands for æther vibrations, but in the sensuous or subjective sense for sensations. The swings are the stimulus, the sensations are the reaction. Between the two comes the link, the "letting off," which it is our business to understand. Here let us remember that the man who first recognized this distinction between the physical and the physiological was not a biologist, but a physicist. It was Young who first made clear (though his doctrine fell on unappreciative ears) that, although in vision the external influences which give rise to the sensation of light are infinitely varied, the responses need not be more than three in number, each being in Müller's language, a "specific energy" of some part of the visual apparatus. We speak of the organ of vision as *highly differentiated*, an expression which carries with it the suggestion of a distinction of rank between different vital processes. The suggestion is a true one, for it would be possible to arrange all those parts or organs of which the bodies of the *higher* animals consist in a series, placing at the lower end of the series those of which the functions are continuous, and therefore called vegetative; at the other, those highly specialized structures, as *e. g.*, those, in the brain, which in response to physical light produce physiological, that is subjective, light; or, to take another instance, the so called motor cells of the surface of the brain, which in response to a stimulus of much greater complexity produce voluntary motion. And just as in civilized society an individual is valued according to his power of doing one thing well, so the high rank which is assigned to the structure, or rather to the "specific energy" which it represents, belongs to it by virtue of its specialization. And if it be asked how this conformity is manifested, the answer is, by the quality, intensity, duration, and extension of the response, in all which respects vision serves as so good an an example, that we can readily understand how it happened that it was in this field that the relation between response and stimulus was first clearly recognized. I need scarcely say that, however interesting it might be to follow out the lines of inquiry thus indicated, we can not attempt it this evening. All that I can do is to mention one or two recent observations which, while they serve as illustrations, may perhaps be sufficiently novel to interest even those who are at home in the subject.

Probably every one is acquainted with some of the familiar proofs that an object is seen for a much longer period than it is actually exposed to view; that the visual reaction lasts much longer than its cause. More precise observations teach us that this response is regulated according to laws which it has in common with all the higher functions of an organism. If, for example, the cells in the brain of the torpedo are "let off"—that is, awakened by an external stimulus—the

electrical discharge, which, as in the case of vision, follows after a certain interval, lasts a certain time, first rapidly increasing to a maximum of intensity, then more slowly diminishing. In like manner, as regards the visual apparatus, we have, in the response to a sudden invasion of the eye by light, a rise and fall of a similar character. In the case of the electrical organ, and in many analogous instances, it is easy to investigate the time relations of the successive phenomena, so as to represent them graphically. Again, it is found that in many physiological reactions, the period of rising "energy" (as Helmholtz called it) is followed by a period during which the responding structure is not only inactive, but its capacity for energizing is so completely lost that the same exciting cause which a moment before "let off" the characteristic response is now without effect. As regards vision, it has long been believed that these general characteristics of physiological reaction have their counterpart in the visual process, the most striking evidence being that in the contemplation of a lightning flash—or better, of an instantaneously illuminated white disk*—the eye seems to receive a double stroke, indicating that although the stimulus is single and instantaneous, the response is reduplicated. The most precise of the methods we until lately possessed for investigating the wax and wane of the visual reation, were not only difficult to carry out but left a large margin of uncertainty. It was therefore particularly satisfactory when M. Charpentier, of Nancy, whose merits as an investigator are perhaps less known than they deserve to be, devised an experiment of extreme simplicity which enables us, not only to observe, but to measure with great facility both phases of the reaction. It is difficult to explain even the simplest apparatus without diagrams; you will however understand the experiment if you will imagine that you are contemplating a disk, like those ordinarily used for color mixing; that it is divided by two radial lines which diverge from each other at an angle of 60°; that the sector which these lines inclose is white, the rest black; that the disk revolves slowly, about once in two seconds. You then see close to the front edge of the advancing sector, a black bar, followed by a second at the same distance from itself but much fainter. Now, the scientific value of the experiment consists in this, that the angular distance of the bar from the black border is in proportion to the frequency of the revolutions—the faster the wider. If, for example, when the disk makes a half revolution in a second the distance is ten degrees, this obviously means that when light bursts into the eye, the extinction happens one-eighteenth of a second after the excitation.†

* The phenomenon is best seen when, in a dark room, the light of a luminous spark is thrown onto a white screen with the aid of a suitable lens.

† Charpentier "Réaction oscillatoire de la Rétine sous l'influence des excitations lumineuses," *Archives de Physiol.*, vol. XXIV, p. 541, and *Propagation de l'action oscillatoire*, etc., p. 362.

The fact thus demonstrated, that the visual reaction consequent on an instantaneous illumination exhibits the alternations I have described, has enabled M. Charpentier to make out another fact in relation to the visual reaction which is, I think, of equal importance. In all the instances, excepting the retina, in which the physiological response to stimulus has a definite time limitation, and in so far resembles an explosion—in other words, in all the higher forms of specific energy, it can be shown experimentally that the process is propagated from the part first directly acted on to other contiguous parts of similar endowment. Thus, in the simplest of all known phenomena of this kind, the electrical change, by which the leaf of the Dionaea plant responds to the slightest touch of its sensitive hairs, is propagated from one side of the leaf to the other, so that in the opposite lobe the response occurs after a delay which is proportional to the distance between the spot excited and the spot observed. That in the retina there is also such propagation has not only been surmised from analogy, but inferred from certain observed facts. M. Charpentier has now been able by a method which, although simple, I must not attempt to describe, not only to prove its existence, but to measure its rate of progress over the visual field.

There is another aspect of the visual response to the stimulus of light which, if I am not trespassing too long on your patience, may, I think, be interesting to consider. As the relations between the sensations of color and the physical properties of the light which excites them, are among the most certain and invariable in the whole range of vital reactions, it is obvious that they afford as fruitful a field for physiological investigation as those in which white light is concerned. We have on one side physical facts, that is, wave lengths or vibration-rates; on the other, facts in consciousness—namely, sensations of color—so simple that notwithstanding their subjective character there is no difficulty in measuring either their intensity or their duration. Between these there are *lines of influence*, neither physical nor psychological, which pass from the former to the latter through the visual apparatus (retina, nerve, brain). It is these lines of influence which interest the physiologist. The structure of the visual apparatus affords us no clews to trace them by. The most important fact we know about them is that they must be at least three in number.

It has been lately assumed by some that vision, like every other specific energy, having been developed progressively, objects were seen by the most elementary forms of eye only in chiaroscuro, that afterwards some colors were distinguished, eventually all. As regards hearing it is so. The organ which, on structural grounds, we consider to represent that of hearing in animals low in the scale of organization—as, *e. g.*, in the Ctenophora—has nothing to do with sound,* but

* Verworn, "Gleichgewicht u. Otolithenorgan," *Pflüger's Archiv.*, vol. 1, 423; also Ewald's Researches on the Labyrinth as a Sense-organ ("Ueber das Endorgan des Nervus octavus," Wiesbaden, 1892).

confers on its possessor the power of judging of the direction of its own movements in the water in which it swims, and of guiding these movememts accordingly. In the lowest vertebrates, as, *e. g.*, in the dogfish, although the auditory apparatus is much more complicated in structure, and plainly corresponds with our own, we still find the particular part which is concerned in hearing scarcely traceable. All that is provided for is that sixth sense, which the higher animals also possess, and which enables them to judge of the direction of their own movements. But a stage higher in the vertebrate series we find the special mechanisms by which we ourselves appreciate sounds beginning to appear—not supplanting or taking the place of the imperfect organ, but added to it. As regards hearing, therefore, a new function is acquired without any transformation or fusion of the old into it. We ourselves possess the sixth sense, by which we keep our balance and which serves as the guide to our bodily movements. It resides in the part of the internal ear which is called the labyrinth. At the same time we enjoy along with it the possession of the cochlea, that more complicated apparatus by which we are able to hear sounds and to discriminate their vibration-rates.

As regards vision, evidence of this kind is wanting. There is, so far as I know, no proof that visual organs which are so imperfect as to be incapable of distinguishing the forms of objects, may not be affected differently by their colors. Even if it could be shown that the least perfect forms of eye possess only the power of discriminating between light and darkness, the question whether in our own such a faculty exists separately from that of distinguishing colors is one which can only be settled by experiment. As in all sensations of color the sensation of brightness is mixed, it is obvious that one of the first points to be determined is whether the latter represents a "specific energy" or merely a certain combination of specific energies which are excited by colors. The question is not whether there is such a thing as white light, but whether we possess a separate faculty by which we judge of light and shade—a question which, although we have derived our knowledge of it chiefly from physical experiment, is one of eye and brain, not of wave-lengths or vibration-rates, and is therefore essentially physiological.

There is a German proverb which says, "Bei Nacht sind alle Katzen grau." The fact which this proverb expresses presents itself experimentally when a spectrum projected on a white surface is watched, while the intensity of the light is gradually diminished. As the colors fade away they become indistinguishable as such, the last seen being the primary red and green. Finally, they also disappear, but a gray band of light still remains, of which the most luminous part is that which before was green.* Without entering into details let us consider what

* Hering, "Untersuch. eines total Farbenblinden," *Pflüger's Arch.*, 1891, vol. XLIX, p. 563.

this tells us of the specific energy of the visual apparatus. Whether or not the faculty by which we see gray in the dark is one which we possess in common with animals of imperfectly developed vision, there seems little doubt that there are individuals of our own species, who, in the fullest sense of the expression, have no eye for color; in whom all color sense is absent; persons who inhabit a world of gray, seeing all things as they might have done had they and their ancestors always lived nocturnal lives. In the theory of color vision, as it is commonly stated, no reference is made to such a faculty as we are now discussing.

Prof. Hering, whose observations as to the diminished spectrum I referred to just now, who was among the first to subject the vision of the *totally* color-blind to accurate examination, is of opinion, on that and on other grounds, that the sensation of light and shade is a specific faculty. Very recently the same view has been advocated on a wide basis by a distinguished psychologist, Prof. Ebbinghaus.* Happily, as regards the actual experimental results relating to both these main subjects, there seems to be a complete coincidence of observation between observers who interpret them differently. Thus the recent elaborate investigations of Capt. Abney† (with Gen. Festing), representing graphically the results of his measurements of the subjective values of the different parts of the diminished spectrum, as well as those of the fully illuminated spectrum as seen by the totally color-blind, are in the closest accord with the observations of Hering, and have moreover been substantially confirmed in both points by the measurements of Dr. König in Helmholtz' laboratory at Berlin.‡ That observers of such eminence as the three persons whom I have mentioned, employing different methods and with a different purpose in view, and without reference to each other's work, should arrive in so complicated an inquiry at coincident results, augurs well for the speedy settlement of this long-debated question. At present the inference seems to be that such a specific energy as Hering's theory of vision postulates actually exists, and that it has for associates the color-perceiving activities of the visual apparatus, provided that these are present; but that whenever the intensity of the illumination is below the chromatic threshold—that is, too feeble to awaken these activities—or when, as in the totally color-blind, they are wanting, it manifests itself independently; all of which can be most easily understood on such a hypothesis as has lately been suggested in an ingenious paper by Mrs. Ladd

* Ebbinghaus, "Theorie des Farbensehens," *Zeitschr f. Psychol.*, 1893, vol. v, p. 145.

† Abney and Festing, Color Photometry, Part III. *Phil. Trans.*, 1891, vol. CLXXXIII, A, p. 531.

‡ König, "Ueber den Helligkeitwerth der Spectralfarben bei verschiedener absoluter Intensität," *Beiträge zur Psychologie*, etc., "Festschrift zu H. von Helmholtz, 70. Geburtstage," 1891, p. 309.

Franklin,* that each of the elements of the visual apparatus is made up of a central structure for the sensation of light and darkness, with collateral appendages for the sensations of color—it being of course understood that this is a mere diagrammatic representation, which serves no purposes beyond that of facilitating the conception of the relation between the several "specific energies."

EXPERIMENTAL PSYCHOLOGY.

Resisting the temptation to pursue this subject further, I will now ask you to follow me into a region which, although closely connected with the subjects we have been considering, is beset with greater difficulties—the subject in which, under the name of physiological or experimental psychology, physiologists and psychologists have of late years taken a common interest—a borderland not between fact and fancy, but between two methods of investigation of questions which are closely related, which here, though they do not overlap, at least interdigitate. It is manifest that, quite irrespectively of any foregone conclusion as to the dependence of mind on processes of which the biologist is accustomed to take cognizance, mind must be regarded as one of the "specific energies" of the organism, and should on that ground be included in the subject-matter of physiology. As however our science, like other sciences, is limited not merely by its subject but also by its method, it actually takes in only so much of psychology as is experimental. Thus sensation (although it is psychological), and the investigation of its relation to the special structures by which the mind keeps itself informed of what goes on in the outside world, have always been considered to be in the physiological sphere. And it is by anatomical researches relating to the minute structure and to the development of the brain, by observation of the facts of disease, and, above all, by physiological experiment, that those changes in the ganglion cells of the brain and spinal cord which are the immediate antecedents of every kind of bodily action have been traced. Between the two (that is, between sensation and the beginning of action), there is an intervening region which the physiologist has hitherto willingly resigned to psychology, feeling his incompetence to use the only instrument by which it can be explored—that of introspection. This consideration enables us to understand the course which the new study (I will not claim for it the title of a new science, regarding it as merely a part of the great science of life) has hitherto followed, and why physiologists have been unwilling to enter on it. The study of the less complicated internal relations of the organism has afforded so many difficult problems that the most difficult of all have been deferred; so that although the psycho-physical method was initiated by E. H. Weber in the mid-

*Christine Ladd Franklin, "Eine neue Theorie der Lichtempfindungen," *Zeitschr für Psychologie*, 1893, vol. IV, p. 211; see also the Proceedings of the last Psychological Congress in London, 1892.

dle of the present century, by investigations * which formed part of the work done at that epoch of discovery, and although Prof. Wundt, also a physiologist, has taken a larger share in the more recent development of the new study, it is chiefly by psychologists that the researches which have given to it its importance as a new discipline have been conducted.

Although therefore experimental psychology has derived its methods from physical science, the result has been not so much that physiologists have become philosophers as that philosophers have become experimental psychologists. In our own universities, in those of America, and still more in those of Germany, psychological students of mature age are to be found who are willing to place themselves in the dissecting room side by side with beginners in anatomy, in order to acquire that exact knowledge of the framework of the organism without which no man can understand its working. Those therefore who are apprehensive lest the regions of mind should be invaded by the *insaniens sapientia* of the laboratory, may, I think, console themselves with the thought that the invaders are for the most part men who, before they became laboratory workers, had already given their allegiance to philosophy; their purpose being not to relinquish definitely, but merely to lay aside for a time the weapons in the use of which they had been trained in order to learn the use of ours. The motive that has encouraged them has not been any hope of finding an experimental solution of any of the ultimate problems of philosophy, but the conviction that inasmuch as the relation between mental stimuli and the mental processes which they awaken is of the same order with the relation between every other vital process and its specific determinant, the only hope of ascertaining its nature must lie in the employment of the same methods of comparative measurement which the biologist uses for similar purposes. Not that there is necessarily anything scientific in mere measurement, but that measurement affords the only means by which it can be determined whether or not the same conformity in the relation between stimulus and reaction which we have accepted as the fundamental characteristic of life is also to be found in mind, notwithstanding that mental processes have no known physical concomitants. The results of experimental psychology tend to show that it is so, and consequently that in so far, the processes in question are as truly functions of organism as the contraction of a muscle, or as the changes produced in the retinal pigment by light.

I will make no attempt even to enumerate the special lines of inquiry which during the last decade have been conducted with such vigor in all parts of the world, all of them traceable to the influence of the Leipzig school, but will content myself with saying that the general

* Weber's researches were published in Wagner's *Handwörterbuch*, I think, in 1849.

purpose of these investigations has been to determine with the utmost attainable precision the nature of psychical relations. Some of these investigations begin with those simpler reactions which more or less resemble those of an automatic mechanism, proceeding to those in which the resulting action or movement is modified by the influence of auxiliary or antagonistic conditions, or changed by the simultaneous or antecedent action on the reagent of other stimuli, in all of which cases the effect can be expressed quantitatively; others lead to results which do not so readily admit of measurement. In pursuing this course of inquiry the physiologist finds himself as he proceeds more and more the *coadjutor* of the psychologist, less and less his *director;* for whatever advantage the former may have in the mere *technique* of observation, the things with which he has to do are revealed only to introspection, and can be studied only by methods which lie outside of his sphere. I might in illustration of this refer to many recent experimental researches—such, for example, as those by which it has been sought to obtain exact data as to the physiological concomitants of pleasure and of pain, or as to the influence of weariness and recuperation, as modifiers of psychological reactions. Another outwork of the mental citadel which has been invaded by the experimental method is that of memory. Even here it can be shown that in the comparison of transitory as compared with permanent memory—as, for example, in the getting off by heart of a wholly uninteresting series of words, with subsequent oblivion and reacquisition—the labor of acquiring and reacquiring may be measured, and consequently the relation between them, and that this ratio varies according to a simple numerical law.

I think it not unlikely that the only effect of what I have said may be to suggest to some of my hearers the question, What is the use of such inquiries? Experimental psychology has, to the best of my knowledge, no technical application. The only satisfactory answer I can give is that it has exercised, and will exercise in future, a helpful influence on the science of life. Every science of observation, and each branch of it, derives from the peculiarities of its methods certain tendencies which are apt to predominate unduly. We speak of this as specialization, and are constantly striving to resist its influence. The most successful way of doing so is by availing ourselves of the counteracting influence which two opposite tendencies mutually exercise when they are simultaneous. He that is skilled in the methods of introspection naturally (if I may be permitted to say so) looks at the same thing from an opposite point of view to that of the experimentalist. It is therefore good that the two should so work together that the tendency of the experimentalist to imagine the existence of mechanism where none is proved to exist—of the psychologist to approach the phenomena of mind too exclusively from the subjective side—may mutually correct and assist each other.

PHOTOTAXIS AND CHEMIOTAXIS.

Considering that every organism must have sprung from a unicellular ancestor, some have thought that unless we are prepared to admit a deferred epigenesis of mind, we must look for psychical manifestations even among the lowest animals, and that as in the protozoon all the vital activities are blended together, mind should be present among them not merely potentially but actually, though in diminished degree.

Such a hypothesis involves ultimate questions which it is unnecessary to enter upon. It will however be of interest in connection with our present subject to discuss the phenomena which served as a basis for it—those which relate to what may be termed the behavior of unicellular organisms and of individual cells, in so far as these last are capable of reacting to external influences. The observations which afford us most information are those in which the stimuli employed can be easily measured, such as electrical currents, light, or chemical agents in solution.

A single instance, or at most two, must suffice to illustrate the influence of light in directing the movements of freely moving cells, or, as it is termed, *Phototaxis*. The rod-like purple organism called by Engelmann *Bacterium photometricum** is such a light-lover that if you place a drop of water containing these organisms under the microscope, and focus the smallest possible beam of light on a particular spot in the field, the spot acts as a light trap and becomes so crowded with the little rodlets as to acquire a deep port-wine color. If, instead of making his trap of white light, he projected on the field a microscopic spectrum, Engelmann found that the rodlets showed their preference for a spectral color, which is absorbed when transmitted through their bodies. By the aid of a light trap of the same kind, the very well known spindle-shaped and flagellate cell of Euglena can be shown to have a similar power of discriminating color, but its preference is different. This familiar organism advances with its flagellum forwards, the sharp end of the spindle having a red or orange eye point. Accordingly, the light it loves is again that which is most absorbed, viz, the blue of the spectrum (line F).

These examples may serve as an introduction to a similar one in which the directing cause of movement is not physical but chemical. The spectral light trap is used in the way already described; the organisms to be observed are not colored, but bacteria of that common sort which twenty years ago we used to call *Bacterium termo*, and which is recognized as the ordinary determining cause of putrefaction. These organisms do not care for light, but are great oxygen-lovers. Consequently, if you illuminate with your spectrum a filament of a confervoid alga, placed in water containing bacteria, the assimilation of

* Engelmann, "Bacterium photometricum," *Onderzoek. Physiol. Lab. Utrecht*, vol. VII, p. 200; also Ueber Licht-u. Farbenperception niederster Organismen, *Pflüger's Arch.*, vol. XXIV, p. 387.

carbon and consequent disengagement of oxygen is most active in the part of the filament which receives the red rays (B to C).

To this part therefore where there is a dark band of absorption, the bacteria which want oxygen are attracted in crowds. The motive which brings them together is their desire for oxygen. Let us compare other instances in which the source of attraction is food.

The plasmodia of the *Myxomycetes*, particularly one which has been recently investigated by Mr. Arthur Lister,* may be taken as a typical instance of what may be called the chemical allurement of living protoplasm. In this organism, which in the active state is an expansion of labile living material, the delicacy of the reaction is comparable to that of the sense of smell in those animals in which the olfactory organs are adapted to an aquatic life. Just as for example the dogfish is attracted by food which it can not see, so the plasmodium of *Badhamia* becomes aware, as if it smelled it, of the presence of its food—a particular kind of fungus. I have no diagram to explain this, but will ask you to imagine an expansion of living material, quite structureless, spreading itself along a wet surface; that this expansion of transparent material is bounded by an irregular coast line; and that somewhere near the coast there has been placed a fragment of the material on which the *Badhamia* feeds. The presence of this bit of *Stereum* produces an excitement at the part of the plasmodium next to it. Towards this center of activity streams of living material converge. Soon the afflux leads to an outgrowth of the plasmodium, which in a few minutes advances towards the desired fragment, envelops, and incorporates it.

May I give you another example also derived from the physiology of plants? Very shortly after the publication of Engelmann's observations of the attraction of bacteria by oxygen, Pfeffer made the remarkable discovery that the movements of the antherozoids of ferns and of mosses are guided by impressions derived from chemical sources, by the allurement exercised upon them by certain chemical substances in solution—in one of the instances mentioned, by sugar, in the other by an organic acid. The method consisted in introducing the substance to be tested, in any required strength, into a minute capillary tube closed at one end, and placing it under the microscope in water inhabited by antherozoids, which thereupon showed their predilection for the substance, or the contrary, by its effect on their movements. In accordance with the principle followed in experimental psychology, Pfeffer† made it his object to determine, not the relative effects of different doses, but the smallest perceptible increase of dose which the organism was able to detect, with this result—that, just as in measurements of the relation between stimulus and reaction in ourselves we find that the sensa-

* Lister, "On the Plasmodium of *Badhamia utricularis*, etc. *Annals of Botany*, No. 5, June, 1888.

† Pfeffer, *Untersuch. a. d. botan. Institute z. Tübingen*, vol. I, part 3, 1884.

tional value of a stimulus depends, not on its absolute intensity, but on the ratio between that intensity and the previous excitation, so in this simplest of vital reagents the same so-called psycho-physical law manifests itself. It is not however with a view to this interesting relation that I have referred to Pfeffer's discovery, but because it serves as a center around which other phenomena, observed alike in plants and animals, have been grouped. As a general designation of reactions of this kind Pfeffer devised the term *Chemotaxis*, or, as we in England prefer to call it, *Chemiotaxis*. Pfeffer's contrivance for chemiotactic testing was borrowed from the pathologists, who have long used it for the purpose of determining the relation between a great variety of chemical compounds or products, and the colorless corpuscles of the blood. I need, I am sure, make no apology for referring to a question which, although purely pathological, is of very great biological interest—the theory of the process by which, not only in man, but also, as Metschnikoff has strikingly shown, in animals far down in the scale of development, the organism protects itself against such harmful things as, whether particulate or not, are able to penetrate its framework. Since Cohnheim's great discovery in 1867 we have known that the central phenomenon of what is termed by pathologists *inflammation* is what would now be called a chemiotactic one; for it consists in the gathering together, like that of vultures to a carcass, of those migratory cells which have their home in the blood stream and in the lymphatic system, to any point where the living tissue of the body has been injured or damaged, as if the products of disintegration which are set free where such damage occurs were attractive to them.

The fact of chemiotaxis therefore as a constituent phenomenon of the process of inflammation, was familiar in pathology long before it was understood. Cohnheim himself attributed it to changes in the channels along which the cells moved, and this explanation was generally accepted, though some writers, at all events, recognized its incompleteness. But no sooner was Pfeffer's discovery known than Leber,* who for years had been working on the subject from the pathological side, at once saw that the two processes were of similar nature. Then followed a variety of researches of great interest, by which the importance of chemiotaxis in relation to the destruction of disease-producing microphytes was proved, that of Buchner† on the chemical excitability of leucocytes being among the most important. Much discussion has taken place, as many present are aware, as to the kind of wandering cells, or leucocytes, which in the first instance attack morbific microbes, and how they deal with them. The question is not by any means decided. It has however I venture to think, been conclusively

* Leber, "Die Anhäufung der Leucocyten am Orte des Entzündungsreizes," etc., *Die Entstehung der Enzündung*, etc., pp. 423–464. Leipzig, 1891.

† Buchner, "Die chem. Reizbarkeit der Leucocyten," etc., *Berliner klin Woch.*, 1890. No. 17.

shown that the process of destruction is a chemical one, that the destructive agent has its source in the chemiotactic cells—that is, cells which act under the orders of chemical stimuli. Two Cambridge observers, Messrs. Kanthack and Hardy,* have lately shown that, in the particular instance which they have investigated, the cells which are most directly concerned in the destruction of morbific *bacilli*, although chemiotactic, do not possess the power of incorporating bacilli or particles of any other kind. While therefore we must regard the relation between the process of devitalizing and that of incorporating as not yet sufficiently determined, it is now no longer possible to regard the latter as essential to the former.

There seems therefore to be very little doubt that chemiotactic cells are among the agents by which the human or animal organism protects itself against infection. There are however many questions connected with this action which have not yet been answered. The first of these are chemical ones—that of the nature of the attractive substance and that of the process by which the living carriers of infection are destroyed. Another point to be determined is how far the process admits of adaptation to the particular infection which is present in each case, and to the state of liability or immunity of the infected individual. The subject is therefore of great complication. None of the points I have suggested can be settled by experiments in glass tubes such as I have described to you. These serve only as indications of the course to be followed in much more complicated and difficult investigations, when we have to do with acute diseases as they actually affect ourselves or animals of similar liability to ourselves, and find ourselves face to face with the question of their causes.

It is possible that many members of the association are not aware of the unfavorable—I will not say discreditable—position that this country at present occupies in relation to the scientific study of this great subject—the causes and mode of prevention of infectious diseases. As regards administrative efficiency in matters relating to public health, England was at one time far ahead of all other countries, and still retains its superiority; but as regards scientific knowledge we are, in this subject as in others, content to borrow from our neighbors. Those who desire either to learn the methods of research or to carry out scientific inquiries, have to go to Berlin, to Munich, to Breslau, or to the Pasteur Institute in Paris, to obtain what England ought long ago to have provided. For to us, from the spread of our race all over the world, the prevention of acute infectious diseases is more important than to any other nation. At the beginning of this address I urged the claims of pure science. If I could, I should feel inclined to speak even more strongly of the application of science to the discovery of the causes of acute diseases. May I express the hope that the effort which is now

* Kanthack and Hardy, "On the Characters and Behavior of the Wandering Cells of the Frog, *Proceedings of the Royal Society*, vol. LII, p. 267.

being made to establish in England an institution for this purpose, not inferior in efficiency to those of other countries, may have the sympathy of all present? And now may I ask your attention for a few moments more to the subject that more immediately concerns us?

CONCLUSION.

The purpose which I have had in view has been to show that there is one principle—that of adaptation—which separates biology from the exact sciences, and that in the vast field of biological inquiry the end we have is not merely, as in natural philosophy, to investigate the relation between the phenomenon and the antecedent and concomitant conditions on which it depends, but to possess this knowledge in constant reference to the interest of the organism. It may perhaps be thought that this way of putting it is too teleological, and that in taking, as it were, as my text this evening so old-fashioned a biologist as Treviranus, I am yielding to a retrogressive tendency. It is not so. What I have desired to insist on is that *organism* is a fact which encounters the biologist at every step in his investigations; that in referring it to any general biological principle, such as adaptation, we are only referring it to itself, not explaining it; that no explanation will be attainable until the conditions of its coming into existence can be subjected to experimental investigation so as to correlate them with those of processes in the non-living world.

Those who were present at the meeting of the British Association at Liverpool, will remember that then, as well as at some subsequent meetings, the question whether the conditions necessary for such an inquiry could be realized was a burning one. This is no longer the case. The patient endeavors which were made about that time to obtain experimental proof of what was called *abiogenesis*, although they conduced materially to that better knowledge which we now possess of the conditions of life of bacteria, failed in the accomplishment of their purpose. The question still remains undetermined; it has, so to speak, been adjourned *sine die*. The only approach to it lies at present in the investigation of those rare instances in which, although the relations between a living organism and its environment ceases as a watch stops when it has not been wound, these relations can be re-established—the process of life re-awakened—by the application of the required stimulus.

I was also desirous to illustrate the relation between physiology and its two neighbors on either side, natural philosophy (including chemistry), and psychology. As regards the latter, I need add nothing to what has already been said. As regards the former, it may be well to notice that, although physiology can never become a mere branch of applied physics or chemistry, there are parts of physiology wherein the principles of these sciences may be applied directly. Thus, in the beginning of the century, Young applied his investigations as to the movements of liquids in a system of elastic tubes directly to the phe-

nomena of the circulation; and a century before, Borelli successfully examined the mechanisms of locomotion and the action of muscles, without reference to any, excepting mechanical principles. Similarly, the foundation of our present knowledge of the process of nutrition was laid in the researches of Bidder and Schmidt, in 1851, by determinations of the weight and composition of the body, the daily gain of weight by food or oxygen, the daily loss by the respiratory and other discharges, all of which could be accomplished by chemical means. But in by far the greater number of physiological investigations, both methods (the physical or chemical and the physiological) must be brought to bear on the same question—to co-operate for the elucidation of the same problem. In the researches, for example, which during several years have occupied Prof. Bohr, of Copenhagen, relating to the exchange of gases in respiration, he has shown that factors purely physical—namely, the partial pressures of oxygen and carbon dioxide in the blood which flows through the pulmonary capillaries—are, so to speak, interfered with in their action by the "specific energy" of the pulmonary tissue in such a way as to render this fundamental process, which, since Lavoisier, has justly been regarded as one of the most important in physiology, much more complicated than we for a long time supposed it to be. In like manner Heidenhain has proved that the process of lymphatic absorption, which before we regarded as dependent on purely mechanical causes—*i. e.*, differences of pressure—is in great measure due to the specific energy of cells, and that in various processes of secretion the principal part is not, as we were inclined not many years ago to believe, attributable to liquid diffusion, but to the same agency. I wish that there had been time to have told you something of the discoveries which have been made in this particular field by Mr. Langley, who has made the subject of "specific energy" of secreting cells his own. It is in investigations of this kind, of which any number of examples could be given, in which vital reactions mix themselves up with physical and chemical ones so intimately that it is difficult to draw the line between them, that the physiologist derives most aid from whatever chemical and physical training he may be fortunate enough to possess.

There is therefore no doubt as to the advantages which physiology derives from the exact sciences. It could scarcely be averred that they would benefit in anything like the same degree from closer association with the science of life. Nevertheless there are some points in respect of which that science may have usefully contributed to the advancement of physics or of chemistry. The discovery of Graham as to the characters of colloid substances and as to the diffusion of bodies in solution through membranes would never have been made had not Graham "plowed," so to speak, "with our heifer." The relations of certain coloring matters to oxygen and carbon dioxide would have been unknown had no experiments been made on the respiration of animals

and the assimilative process in plants; and, similarly, the vast amount of knowledge which relates to the chemical action of ferments must be claimed as of physiological origin. So, also, there are methods, both physical and chemical, which were originally devised for physiological purposes. Thus the method by which meteorological phenomena are continuously recorded graphically originated from that used by Ludwig (1847) in his "Researches on the Circulation;" the mercurial pump, invented by Lothar Meyer, was perfected in the physiological laboratories of Bonn and Leipsic; the rendering the galvanometer needle aperiodic by damping was first realized by du Bois-Reymond—in all of which cases invention was prompted by the requrements of physiological research.

Let me conclude with one more instance of a different kind, which may serve to show how perhaps the wonderful ingenuity of contrivance which is displayed in certain organized structures—the eye, the ear, or the organ of voice—may be of no less interest to the physicist than to the physiologist. Johannes Müller, as is well known, explained the compound eye of insects on the theory that an erect picture is formed on the convex retina by the combination of pencils of light received from different parts of the visual field through the eyelets (ommatidia) directed to them. Years afterwards it was shown that in each eyelet an image is formed which is reversed. Consequently the mosaic theory of Müller was for a long period discredited on the ground that an erect picture could not be made up of "upside-down" images. Lately the subject has been re-investigated, with the result that the mosaic theory has regained its authority. Prof. Exner* has proved photographically that behind each part of the insect's eye an erect picture is formed of the objects towards which it is directed. There is therefore no longer any difficulty in understanding how the whole field of vision is mapped out as consistently as it is imaged on our own retina, with the difference, of course, that the picture is erect. But behind this fact lies a physical question—that of the relation between the erect picture which is photographed and the optical structure of the crystal cones which produce it—a question which, although we can not now enter upon it, is quite as interesting as the physiological one.

With this history of a theory which, after having been for thirty years disbelieved, has been re-instated by the fortunate combination of methods derived from the two sciences, I will conclude. It may serve to show how, though physiology can never become a part of natural philosophy, the questions we have to deal with are cognate. Without forgetting that every phenomenon has to be regarded with reference to its useful purpose in the organism, the aim of the physiologist is not to inquire into final causes, but to investigate processes. His question is ever How rather than Why.

*Exner, "Die Physiologie der facettirten Augen von Krebsen u. Insecten," Leipsic, 1891.

May I illustrate this by a simple, perhaps too trivial, story, which derives its interest from its having been told of the childhood of one of the greatest natural philosophers of the present century?* He was even then possessed by that insatiable curiosity which is the first quality of the investigator, and it is related of him that his habitual question was, "What is the *go* of it?" and, if the answer was unsatisfactory, "What is the particular go of it?" That north country boy became Prof. Clerk Maxwell. The questions he asked are those which, in our various ways, we are all trying to answer.

* "Life of Clerk Maxwell" (Campbell and Garnett), p. 28.

FIELD STUDY IN ORNITHOLOGY.*

By H. B. Tristram, F. R. S.

It is difficult for the mind to grasp the advance in biological science (I use the term biology in its wide etymological, not its recently restricted sense) which has taken place since I first attended the meetings of the British Association, some forty years ago. In those days the now familiar expressions of "natural selection," "isolation," "the struggle for existence," "the survival of the fittest," were unheard of and unknown, though many an observer was busied in culling the facts which were being poured into the lap of the philosopher who should mold the first great epoch in natural science since the days of Linnæus.

It is to the importance and value of field observation that I would venture in the first place to direct your attention.

My predecessors in this chair have been, of recent years, distinguished men who have searched deeply into the abstrusest mysteries of physiology. Thither I do not presume to follow them. I rather come before you as a survivor of the old-world naturalist, as one whose researches have been, not in the laboratory or with the microscope, but on the wide desert, the mountain side, and the isles of the sea.

This year is the centenary of the death of Gilbert White, whom we may look upon as the father of field naturalists. It is true that Sir T. Browne, Willughby, and Ray had each, in the middle of the seventeenth century, committed various observations to print; but though Willughby, at least, recognized the importance of the soft parts in affording a key to classification, as well as the osteology, as may be seen from his observation of the peculiar formations, in the Divers (*Colymbidæ*) of the tibia, with its prolonged procnemial process, of which he has given a figure, or his description of the elongation of the posterior branches of the woodpecker's tongue, as well as by his careful description of the intestines of all specimens which came under his notice in the flesh,

* Opening address before the British Association for the Advancement of Science; at Notingham, September, 1893, by the president of the Section of Biology. (From *The Zoologist*, London, October, 1893, vol. XVII, pp. 361-386; and *Nature*, September 21, 1893, vol. XLVIII, pp. 490.)

none of these systematically noted the habits of birds apart from an occasional mention of their nidification, and very rarely do they even describe the eggs. But White was the first observer to recognize how much may be learned from the life habits of birds. He is generally content with recording his observations, leaving to others to speculate. Fond of Virgilian quotations (he was a fellow of Oriel of the last century), his quotations are often made with a view to prove the scrupulous accuracy of the Roman poet, as tested by his (White's) own observations.

In an age incredulous as to that which appears to break the uniformity of nature, but quick to recognize all the phenomena of life, a contrast arises before the mind's eye between the abiding strength of the objective method, which brings Gilbert White in touch with the great writers whose works are for all time and the transient feebleness of the modern introspective philosophies, vexed with the problems of psychology. The modern psychologist propounds his theory of man and the universe, and we read him and go on our way, and straightway forget. Herodotus and Thucydides tell a plain tale in plain language, or the Curate of Selborne shows us the hawk on the wing, or the snake in the grass, as he saw them day by day, and somehow the simple story lives and moves him who reads it long after the subtleties of this or that philosophical theory have had their day and passed into the limbo of oblivion. But, invaluable as has been the example of Gilbert White in teaching us how to observe, his field was a very narrow one, circumscribed for the most part by the boundaries of a single parish, and on the subject of geographical distribution (as we know it now) he could contribute nothing, a subject on which even the best explorers of that day were strangely inobservant and inexact.

AVIAN DISTRIBUTION.

A century and a half ago, it had not come to be recognized that distribution is (along of course with morphology and physiology) a most important factor in determining the facts of biology. It is difficult to estimate what might have been gained in the case of many species, now irreparably lost, had Forster and the other companions of Capt. Cook, to say nothing of many previous voyagers, had the slightest conception of the importance of noting the exact locality of each specimen they collected. They seem scarcely to have recognized the specific distinctions of the characteristic genera of the Pacific Islands at all, or if they did, to have dismissed them with the remark, "On this island was found a flycatcher, a pigeon, or a parrot similar to those found in New Holland, but with white tail feathers instead of black, an orange instead of a scarlet breast, or red shoulders instead of yellow." As we turn over the pages of Latham or Shaw, how often do we find for locality one of the islands of the South Sea, and, even where the locality is given, subsequent research has proved it erroneous, as though the speci-

mens had been subsequently ticketed; Le Vaillant described many of his South African birds from memory. Thus Latham, after describing very accurately *Rhipidura flabellifera*, from the south island of New Zealand, remarks, apparently on Forster's authority, that it is subject to variation; that in the island of Tanna another was met with, with a different tail, etc., and that there was another variety in the collection of Sir Joseph Banks. Endless perplexity has been caused by the *Psittacus pygmaeus* of Gmelin (of which Latham's type is at Vienna) being stated in the inventory as from Botany Bay, by Latham from Otaheite, and in his book as inhabiting several of the islands of the South Seas, and now it proves to be the female *Psittacus palmarum* from the New Hebrides. These are but samples of the confusion caused by the inaccuracies of the old voyagers. Had there been in the first crew who landed on the island of Bourbon, I will not say a naturalist, but even a simple-hearted Leguat, to tell the artless tale of what he saw, or had there been among the Portuguese discoverers of Mauritius one who could note and describe the habits of its birds with the accuracy with which a Poulton could record the ways and doings of our Lepidoptera, how vastly would our knowledge of a perished fauna have been enriched! It is only since we learned from Darwin and Wallace the power of isolation in the differentiation of species, that special attention has been paid to the peculiarities of insular forms. Here the field naturalist comes in as the helpful servant of the philosopher and the systematist, by illustrating the operation of isolation in the differentiation of species. I may take the typical examples of two groups of oceanic islands, differing as widely as possible in their position on the globe—the Sandwich Islands, in the center of the Pacific, thousands of miles from the nearest continent, and the Canaries, within sight of the African coast—but agreeing in origin, the ocean depths close to the Canaries and between the different islands varying from 1,500 to 2,000 fathoms. In the one we may study the expiring relics of an avifauna completely differentiated by isolation; in the other we have the opportunity of tracing the incipient stages of the same process.

The Sandwich Islands have long been known as possessing an avifauna not surpassed in interesting peculiarity by that of New Zealand or Madagascar; in fact, it seems as though their vast distance from the continent had intensified the influences of isolation. There is scarcely a passerine bird in its indigenous fauna which can be referred to any genus known elsewhere. But until the very recent researches of Mr. Scott Wilson and the explorations of the Hon. W. Rothschild's collectors it was not known that almost every island of the group possessed one or more representatives of each of these peculiar genera. Thus every island which has been thoroughly explored, and in which any extent of the primeval forest remains, possesses or has possessed its own peculiar species of *Hemignathus*, *Himatione*, *Phaeornis*, *Acrulocercus*, *Loxops*, *Drepanis*, as well as of the massive-beaked finches,

which emulate the *Geospiza* of the Galapagos. Prof. Newton has shown that while the greater number of those are probably of American origin, yet the South Pacific has contributed its quota to this museum of ornithological rarities, which Mr. Clarke very justly proposes to make a distinct biological subregion.

That each of the islands of this group, however small, should possess a flora specifically distinct suggests thoughts of the vast periods occupied in their differentiation.

In the Canary Islands, either because they are geologically more recent or because of their proximity to the African coast, which has facilitated frequent immigrations from the continent, the process of differentiation is only partially accomplished. Yet there is scarcely a resident species which is not more or less modified, and this modification is yet further advanced in the westernmost islands than in those nearest to Africa. In Fuertaventura and Lanzarote, waterless and treeless, there is little change, and the fauna is almost identical with that of the neighbouring Sahara. There is a whinchat, *Pratincola dacotiæ*, discovered by my companion, Mr. Meade-Waldo, peculiar to Fuertaventura, which may possibly be found on the opposite coast, though it has not yet been met with by any collectors there. Now, our whinchat is a common winter visitant all down the West African coast, and it seems probable that isolation has produced the very marked characters of the Canaries form, while the continental individuals have been restrained from variation by their frequent association with their migratory relations. A similar cause may explain why the blackbird, an extremely common resident in all the Canary Islands, has not been modified in the least, since many migratory individuals of the same species sojourn every winter in the islands. Or take the blue titmouse. Our familiar resident is replaced along the coast of North Africa by a representative species, *Parus ultra-marinus*, differentiated chiefly by a black instead of a blue cap and a slate-colored instead of a green back. The titmouse of Lanzarote and Fuertaventura is barely separable from that of Algeria, but is much smaller and paler, probably owing to scarcity of food and a dry desert climate. Passing 100 miles farther to sea, to Grand Canary, we find in the woods and forests a bird in all respects similar to the Algerian in color and dimensions, with one exception: the greater wing coverts of the Algerian are tipped with white, forming a broad bar when the wing is closed. This, present in the Fuertaventura form, is represented in the Canarian by the faintest white tips, and in the birds from the next islands, Teneriffe and Gomera, this is altogether absent. This form has been recognized as *Parus teneriffæ*. Proceeding to the northwest outermost island, Palma, we find a very distinct species, with different proportions, a longer tail, and white abdomen instead of yellow. In the ultima Thule, Hierro, we find a second very distinct species, resembling that of Teneriffe in the absence of the wing bar, and in all other respects, except that the

back is green, like the European, instead of slate, as in all the other species. Thus we find in this group a uniform graduation of variation as we proceed further from the cradle of the race.

A similar series of modifications may be traced in the chaffinch (*Fringilla*), which has been in like manner derived from the North African *F. spodiogena*, and in which the extreme variation is to be found in the westernmost islands of Palma and Hierro. The willow wren (*Phylloscopus trochilus*), extremely numerous and resident, has entirely changed its habits, though not its plumage, and I have felt justified in distinguishing it as *Ph. fortunatus.* In note and habits it is entirely different from our bird, and though it builds a domed nest it is always near the top of lofty trees, most frequently in palm trees. The only external difference from our bird consists in its paler tarsi and more rounded wing, so that its power of flight is weaker, but, were it not for the marked difference in his habits and voice, I should have hesitated to differentiate it. In the kestral and the great spotted woodpecker there are differences which suggest incipient species, while the forests of the wooded western islands yield two very peculiar pigeons, differing entirely from each other in their habits, both probably derived from our woodpigeon, but even further removed from it than the *Columba trocaz* of Madeira, and by their dark chestnut coloration suggesting that peculiar food, in this case the berries of the tree laurel, has its full share in the differentiation of isolated forms. If we remember the variability of the pigments in the food of birds and the amount absorbed and transferred to the skin and plumage, the variability in the tints and patterns of many animals can be more readily understood.

One other bird deserves notice, the *Caccabis*, or red-legged partridge, for here, and here alone, we have chronological data. The Spaniards introduced *Caccabis rufa* into Canary and *C. petrosa* into Teneriffe and Gomera, and they have never spread from their respective localities. Now, both species, after a residence of only four hundred years, have become distinctly modified. *C. rufa* was introduced into the Azores also, and changed exactly in the same manner, so much so that Mr. Godman, some years ago, would have described it as distinct, but that the only specimen he procured was in molt and mutilated, and his specimen proved identical with the Canarian bird. Besides minor differences, the back is one-fourth stouter and longer than in the European bird, and the tarsus very much stouter and longer, and the back is gray rather than russet. The gray back harmonizes with the volcanic dark soil of the rocks of the Canaries, as the russet does with the clay of the plains of England and France. In the Canaries the bird lives under different conditions from those of Europe. It is on the mountain sides and among rocks that the stouter beak and stronger legs are indispensable to its vigorous existence. It is needless to go into the details of many other species. We have here the

effect of changed conditions of life in four hundred years. What may they not have been in four hundred centuries? We have the result of peculiar food in the pigeons and of isolation in all the cases I have mentioned. Such facts can only be supplied to the generalizer and the systematist through the accurate and minute observations of the field naturalist.

The character of the avi-fauna of the Comoro Islands, to take another insular group, seems to stand midway in the differentiating process between the Canaries and the Sandwich Islands. From the researches of M. Humblot, worked out by MM. Milne-Edwards and Oustalet, we find that there are 29 species acknowledged as peculiar; 2 species from South Africa and 22 from Madagascar in process of specification, called by M. Milne-Edwards secondary, or derived, species.

The little Christmas Island, an isolated rock 200 miles south of Java, only 12 miles in length, has been shown by Mr. Lister to produce distinct and peculiar forms of every class of life, vegetable and animal. Though the species are few in number, yet every mammal and land bird is endemic; but, as Darwin remarks, to ascertain whether a small isolated area or a large open area like a continent has been more favorable for the production of new organic forms, we ought to make the comparison between equal times, and this we are incapable of doing. My own attention was first directed to this subject when, in the year 1857–'58, I spent many months in the Algerian Sahara, and noticed the remarkable variations in different groups according to elevation from the sea and the difference of soil and vegetation. The Origin of Species had not then appeared, but on my return my attention was called to the communication of Darwin and Wallace to the Linnaean Society on the tendencies of species to form varieties and on the perpetuation of varieties and species by means of natural selection. I then wrote (*Ibis*, 1859, pp. 429–433):

"It is hardly possible, I should think, to illustrate this theory better than by the larks and chats of North Africa. In all these, in the congeners of the wheatear, of the rock chat, of the crested lark, we trace gradual modifications of coloration and of anatomical structure, deflecting by very gentle gradations from the ordinary type, but when we take the extremes presenting the most marked differences. - - - In the desert, where neither trees, brushwood, nor even undulations of surface afford the slightest protection to an animal from its foes, a modification of colors, which shall be assimilated to that of the surrounding country, is absolutely necessary. Hence, without exception, the upper plumage of every bird—whether lark, chat, sylvan, or land grouse—and also the fur of all the small mammals and the skin of all the snakes and lizards, is of the uniform isabelline or sand color. It is very possible that some further purpose may be served by the prevailing colors, but this appears of itself a sufficient explanation. There are individual varieties of depth of hue among all creatures. In the struggle for life which we know to be going on among all species a very slight change for the better, such as improved means of escape from its natural enemies (which would be the effect of an alteration from a con-

spicuous color to one resembling the hue of the surrounding objects), would give the variety that possessed it a decided advantage over the typical or other forms of the species. - - - To apply the theory to the case of the Sahara. If the Algerian desert were colonized by a few pairs of crested larks—putting aside the ascertained fact of the tendency of an arid, hot climate to bleach all dark colors—we know that the probability is that one or two pairs would be likely to be of a darker complexion than the others. These and such of the offspring as most resembled them would become more liable to capture by their natural enemies—hawks and carnivorous beasts. The lighter colored ones would enjoy more or less immunity from such attacks. Let this state of things continue for a few hundred years and the dark-colored individuals would be exterminated, the light-colored remain and inherit the land. This process, aided by the above-mentioned tendency of the climate to bleach the coloration still more, would, in a few centuries, produce the *Galerida abyssinica* as the typical form; and it must be noted that between it and the European *G. cristata* there is no distinction but that of color.

"But when we turn to *Galerida isabellina*, *G. arenicola*, and *G. macrorhyncha*, we have differences not only of color, but of structure. These differences are most marked in the form of the bill. Now, to take the two former first, *G. arenicola* has a very long bill, *G. isabellina* a very short one. The former resorts exclusively to the deep, loose, sandy tracts; the latter haunts the hard and rocky districts. It is manifest that a bird whose food has to be sought for in deep sand derives a great advantage from any elongation, however slight, of its bill. The other, who feeds among stones and rocks, requires strength rather than length. We know that even in the type species the size of the bill varies in individuals—in the lark as well as in the snipe. Now, in the desert the shorter-billed varieties would undergo comparative difficulty in finding food where it was not abundant, and consequently would not be in such vigorous condition as their longer-billed relation. In the breeding season, therefore, they would have fewer eggs and a weaker progeny. Often, as we know, a weakly bird will abstain from matrimony altogether. The natural result of these causes would be that in course of time the longest-billed variety would steadily predominate over the shorter, and in a few centuries they would be the sole existing race, their shorter-billed fellows dying out until that race is extinct. The converse will still hold good of the stout billed and weaker billed varieties in a rocky district.

"Here are only two causes enumerated which might serve to create, as it were, a new species from an old one. Yet they are perfectly natural causes, and such as I think must have occurred and are possibly occurring still. We know so very little of the causes which, in the majority of cases, make species rare or common that there may be hundreds of others at work, some even more powerful than these, which go to perpetuate and eliminate certain forms 'according to natural means of selection.'"

It would appear that those species in continental areas are equally liable to variation with those which are isolated in limited areas, yet that there are many counteracting influences which operate to check this tendency. It is often assumed, where we find closely allied species apparently interbreeding at the center of their area, that the blending of forms is caused by the two races commingling. Judging from

insular experience, I should be inclined to believe that the theory of interbreeding is beginning at the wrong end, but rather that, while the generalized forms remain in the center of distribution, we find more decidedly distinct species at the extremes of the range, caused not by interbreeding, but by differentiation. To illustrate this by the group of the blue titmouse. We find in Central Russia, in the center of distribution of the family, the most generalized form, *Parus pleskii*, partaking of the characters of the various species east, west, and south. In the northeast and north it becomes differentiated as *P. cyaneus;* to the southwest and south into *P. cœruleus* and its various subspecies, while a branch extending due east has assumed the form of *P. flavipectus*, bearing traces of affinity to its neighbor *P. cyaneus* in the north, which seems evidently to have been derived from it.

But the scope of field observation does not cease with geographical distribution and modification of form. The closest systematist is very apt to overlook or to take no count of habits, voice, modification, and other features of life which have an important bearing on the modification of species. To take one instance, the short-toed lark (*Calandrella brachydactyla*) is spread over the countries bordering on the Mediterranean; but along with it, in Andalusia alone is found another species, *Cal. bætida*, of a rather darker color, and with the secondaries generally somewhat shorter. Without further knowledge than that obtained from a comparison of skins, it might be put down as an accidental variety. But the field naturalist soon recognizes it as a most distinct species. It has a different voice, a differently shaped nest; and, while the common species breeds in the plains, this one always resorts to the hills. The Spanish shepherds on the spot recognize their distinctness, and have a name for each species. Take, again, the eastern form of the common song thrush. The bird of North China, *Turdus auritus*, closely resembles our familiar species, but is slightly larger, and there is a minute difference in the wing formula. But the field naturalist has ascertained that it lays eggs like those of the missel-thrush, and it is the only species closely allied to our bird which does not lay eggs of a blue ground color. The hedge accentor of Japan (*Accentor rubidus*) is distinguished from our most familiar friend, *Accentor modularis*, by delicate differences of hue. But, though in gait and manner it closely resembles it, I was surprised to fine the Japanese bird strikingly distinct in habits and life, being found only in forest and brushwood several thousand feet above the sea. I met with it first at Chinsenze—6,000 feet, before the snow had left the ground, and in summer it goes higher still, but never descends to the cultivated land. If both species are derived, as seems probable, from *Accentor immaculatus* of the Himalayas, then the contrast in habits is easily explained. The lofty mountain ranges of Japan have enabled the settlers there to retain their original habits, for which our humbler elevations have afforded no scope.

BIRD MIGRATION.

On the solution of the problem of the migration of birds, the most remarkable of all the phenomena of animal life, much less aid has been contributed by the observations of field naturalists that might reasonably have been expected. The facts of migration have, of course, been recognized from the earliest times, and have afforded a theme for Hebrew and Greek poets three thousand years ago. Theories which would explain it are rife enough, but it is only of late years that any systematic effort has been made to classify and summarize the thousands of data and notes which are needed in order to draw any satisfactory conclusion. The observable facts may be classified as to their bearing on the whither, when, and how, of migration, and after this we may possibly arrive at a true answer to the Why? Observation has sufficiently answered the first question, Whither?

There are scarcely any feathered denizens of earth or sea to the summer and winter ranges of which we can not now point. Of almost all the birds of the holo-arctic fauna, we have ascertained the breeding places and the winter resorts. Now that the knot and the sanderling have been successfully pursued even to Grinnell Land, there remains but the curlew sandpiper (*Tringa subarquata*), of all the known European birds, whose breeding ground is a virgin soil, to be trodden, let us hope, in a successful exploration by Nansen, on one side or other of the North Pole. Equally clearly ascertained are the winter quarters of all the migrants. The most casual observer can not fail to notice in any part of Africa, north or south, west coast or interior, the myriads of familiar species which winter there. As to the time of migration, the earliest notes of field naturalists have been the records of the dates of arrival of the feathered visitors. We possess them for some localities, as for Norfolk by the Marsham family, so far back as 1736. In recent years these observations have been carried out on a larger and more systematic scale by Middendorf, who, forty years ago, devoted himself to the study of the lines of migration in the Russian Empire, tracing what he called the *isopipteses*, the lines of similtaneous arrival of particular species, and by Prof. Palmén, of Finland, who, twenty years later, pursued a similar course of investigation; and by Prof. Baird on the migration of North American birds; and subsequently by Severtzoff as regards central Asia, and Menzbier as regards eastern Europe. As respects our own coasts, a vast mass of statistics has been collected by the labors of the migration committee appointed by the British Association in 1880, for which our thanks are due to the indefatigable zeal of Mr. John Cordeaux and his colleague Mr. John Harvie Brown, the originators of the scheme by which the light-houses were for nine years used as posts of observation on migration. The reports of that committee are familiar to us, but the inferences are not yet worked out. I can not but regret that the committee has been allowed to drop. Prof.

W. W. Cooke has been carrying on similar observations in the Mississippi Valley, and others, too numerous to mention, have done the same elsewhere. But, as Prof. Newton has truly said, all these efforts may be said to pale before the stupendous amount of information amassed during more than fifty years by the venerable Herr Gätke, of Heligoland, whose work we earnestly desire may soon appear in an English version.

We have, through the labors of the writers I have named, and many others, arrived at a fair knowledge of the When? of migration. Of the How? we have ascertained a little, but very little. The lines of migration vary widely in different species, and in different longitudes. The theory of migration being directed toward the magnetic pole, first started by Middendorff, seems to be refuted by Baird, who has shown that in North America the theory will not hold. Yet, in some instances, there is evidently a converging tendency in northward migrations. The line, according to Middendorff, in middle Siberia is due north, in eastern Siberia southeast to northwest, and in western Siberia from southwest to northeast. In European Russia Menzbier traces four northward routes: (1) A coast line coming up from Norway round the North Cape to Nova Zembla. (2) The Baltic line with bifurcation, one proceeding by the Gulf of Bothnia, and the other by the Gulf of Finland, which is afterwards again subdivided. (3) A Black Sea line, reaching nearly as far north as the valley of the Petchora; and (4) the Caspian line, passing up the Volga, and reaching as far east as the valley of the Obi by other anastomosing streams.

Palmén has endeavored to trace the lines of migration on the return autumnal journey in the Eastern Hemisphere, and has arranged them in nine routes: (1) From Nova Zembla, round the west of Norway, to the British Isles. (2) From Spitzbergen, by Norway, to Britain, France, Portugal, and West Africa. (3) From North Russia, by the Gulf of Finland, Holstein, and Holland, and then bifurcating to the west coast of France on the one side, and on the other up the Rhine to Italy and North Africa. (4*a*) Down the Volga by the Sea of Azof, Asia Minor, and Egypt, while the other portion (4*b*), trending east, passes by the Caspian and Tigris to the Persian Gulf. (5) By the Yenesei to Lake Baikal and Mongolia. (6) By the Lena on to the Amoor and Japan. (7) From East Siberia to the Corea and Japan. (8) Kamschatka to Japan and the Chinese coast. (9) From Greenland, Iceland, and the Farohs, to Britain, where it joins line 2.

All courses of rivers of importance from minor routes, and consideration of these lines of migration might serve to explain the fact of North American stragglers, the waifs and strays which have fallen in with great flights of the regular migrants and been more frequently shot on the east coast of England and Scotland than on the west coast or in Ireland. They have not crossed the Atlantic, but have come from the far north, where a very slight deflection east or west might alter their

whole course, and in that case they would naturally strike either Iceland or the west coast of Norway, and in either case would reach the east coast of Britain. But, if by storms, and the prevailing winds of the North Atlantic coming from the west, they had been driven out of their usual course, they would strike the coast of Norway, and so find their way hither in the company of their congeners.

As to the elevation at which migratory flights are carried on, Herr Gätke, as well as many American observers, holds that it is generally far above our ken, at least in normal conditions of the atmosphere, and that the opportunities of observation, apart from seasons and unusual atmospheric disturbance, are confined chiefly to unsuccessful and abortive attempts. It is maintained that the height of flight is some 1,500 to 15,000 feet, and if this be so, as there seems every reason to admit, the aid of land bridges and river valleys becomes of very slight importance. A trivial instance will illustrate this. There are two species of blue-throat, *Cyanecula suecica* and *C. leucocyana;* the former with its red-breast patch is abundant in Sweden in summer, but is never found in Germany, except most accidentally, as the other is the common form of central Europe. Yet both are abundant in Egypt and Syria, where they winter, and I have on several occasions obtained both species out of the same flock. Hence we infer that the Swedish bird makes its journey from its winter quarters with scarcely a halt, while the other proceeds leisurely to its nearer summer quarters. On the other hand, I have more than once seen myriads of swallows, martins, sand-martins, and, later in the season, swifts, passing up the Jordan Valley and along the Bukoa of central Syria, at so slight an elevation that I was able to distinguish at once that the flight consisted of swallows or house-martins. This was in perfectly calm, clear weather. One stream of swallows, certainly not less than a quarter of a mile wide, occupied more than half an hour in passing over one spot, and flights of house-martins, and then of sand-martins, the next day, were scarcely less numerous. These flights must have been straight up from the Red Sea, and may have been the general assembly of all those which had wintered in East Africa. I can not think that these flights were more than 1,000 feet high. On the other hand, when standing on the highest peak in the island of Palma, 6,500 feet, with a dense mass of clouds beneath us, leaving nothing of land or sea visible, save the distant Peak of Tenerife, 13,000 feet, I have watched a flock of Cornish choughs soaring above us, till at length they were absolutely indistinguishable by us except with field-glasses.

As to the speed with which the migration flights are accomplished, they require much further observation. Herr Gätke maintains that godwits and plovers can fly at the rate of 240 miles an hour (!), and the late Dr. Jerdon stated that the spine-tailed swift (*Acanthyllis caudacutus*), roosting in Ceylon, would reach the Himalayas (1,200 miles) before sunset. Certainly in their ordinary flight the swift is the only

bird I have ever noticed to outstrip an express train on the Great Northern Railway.

Observation has shown us that, while there is a regular and uniform migration in the case of some species, yet that, beyond these, there comes a partial migration of some species, immigrants and emigrants simultaneously, and this, besides the familiar vertical emigration from higher to lower altitudes and *vice versa*, as in the familiar instance of the lapwing and golden plover. There is still much scope for the field naturalist in observation of these partial migrations. There are also species in which some individuals migrate and some are sedentary, *e. g.*, in the few primeval forests which still remain in the Canary Islands, and which are enshrouded in almost perpetual mist, the woodcock is sedentary and not uncommon. I have often put up the bird and seen the eggs; but in winter the number is vastly increased, and the visitors are easily to be distinguished from the residents by their lighter color and larger size. The resident never leaves the cover of the dense forest, where the growth of ferns and shrubs is perpetual and fosters a moist, rich, semipeaty soil, in which the woodcock finds abundant food all the year, and has thus lost its migratory instincts.

But why do birds migrate? Observation has brought to light many facts which seem to increase the difficulties of a satisfactory answer to the question. The autumnal retreat from the breeding quarters might be explained by a want of sufficient sustenance as winter approaches in the higher latitudes, but this will not account for the return migration in the spring, since there is no perceptible diminution of supplies in the winter quarters. A friend of mine, who was for some time stationed at an infirmary at Kikombo, on the high plateau southeast of Victoria Nyanza Lake, almost under the equator, where there is no variation in the seasons, wrote to me that from November to March the country swarmed with swallows and martins, which seemed to the casual observer to consist almost wholly of our three species, though occasionally a few birds of different type might be noticed in the larger flocks. Towards the end of March, without any observable change in climatic or atmospheric conditions, nine-tenths of the birds suddenly disappeared, and only a sprinkling remained. These, which had previously been lost amid the myriad of winter visitants, seemed to consist of four species, of which I received specimens of two, *Hirundo puella* and *H. senegalensis*. One, described as white underneath, is probably *H. æthiopica*; and the fourth, very small and quite black, must be a *Psalidoprocne*. All these remained through spring and summer. The northward movement of all the others must be through some impulse not yet ascertained. In many other instances observation has shown that the impulse of movement is not dependent on the weather at the moment. This is especially the case with sea birds. Prof. Newton observes that they can be trusted as the almanac itself. Foul weather or fair, heat or cold, the puffins, *Fratercula arctica*, repair to some of

their stations punctually on a given day, as if their movements were regulated by clock-work. In like manner, whether the summer be cold or hot, the swifts leave their summer home in England about the first week in August, only occasional stragglers ever being seen after that date. So in three different years I noticed the appearance of the common swift (*Cypselus apus*) in myriads on one day in the first week in April. In the case of almost all the land birds it has been ascertained by repeated observations that the male birds arrive some days before the hens. I do not think it is proved that they start earlier; but being generally stronger than the females, it is very natural that they should outstrip their weaker mates. I think, too, that there is evidence that those species which have the most extended southerly, have also the most extended northerly range. The same may hold good of individuals of the same species, and may be accounted for by, or account for, the fact that, *e. g.*, the individuals of the wheatear or the willow wren which penetrate farthest north have longer and stronger wings than those individuals which terminate their journey in more southern latitudes. The length of wing of two specimens of *Saxicola œnanthe* in my collection from Greenland and Labrador exceeds by 0·6 inch the length of the British and Syrian specimens, and the next longest, exceeding them by 0·5 inch, is from the Gambia. So the sedentary *Phylloscopus trochilus* of the Canaries has a perceptibly shorter wing than European specimens.

To say that migration is performed by instinct is no explanation of the marvellous faculty; it is an evasion of the difficulty. Prof. Möbius holds that birds crossing the ocean may be guided by observing the rolling of the waves, but this will not hold good in the varying storms of the Atlantic; still less in the vast stretch of stormy and landless ocean crossed by the bronze cuckoo (*Chrysococcyx lucidus*) in its passage from New Guinea to New Zealand. Prof. Palmén ascribes the due performance of the flight to experience, but this is not confirmed by field observers. He assumes that the flights are led by the oldest and strongest, but observation by Herr Gatke has shown that among migrants, as the young and old journey apart and by different routes, the former can have had no experience. All ornithologists are aware that the parent cuckoos leave this country long before their young ones are hatched by their foster-parents. The sense of sight can not guide birds which travel by night, or span oceans or continents in a single flight. In noticing all the phenomena of migration, there yet remains a vast untilled region for the field naturalist.

What Prof. Newton terms the sense of direction, unconsciously exercised, is the nearest approach yet made to a solution of the problem. He remarks how vastly the sense of direction varies in human beings, contrasting its absence in the dwellers in towns compared with the power of the shepherd and the countryman, and, infinitely more, with the power of the savage or the Arab. He adduces the experience

of Middendorff among the Samojeds, who know how to reach their goal by the shortest way through places wholly strange to them. He had known it among dogs and horses (as we may constantly perceive), but was surprised to find the same incomprehensible animal faculty unweakened among uncivilized men. Nor could the Samojeds understand his inquiry how they did it. They disarmed him by the question, How now does the Arctic fox find its way aright on the tundra, and never go astray? And Middendorff adds, "I was thrown back on the unconscious performance of an inherited animal faculty;" and so are we!

There is one more kind of migration, of which we know nothing, and where the field naturalist has still abundant scope for the exercise of observation. I mean what is called exceptional migration—not the mere wanderings of waifs and strays, nor yet the uncertain travels of some species, as the crossbill in search of food, but the colonizing parties of many gregarious species, which generally, so far as we know in our own hemisphere, travel from east to west, or from southeast to northwest. Such are the waxwing (*Ampelis garrula*), the pastor starling (*Pastor roseus*), and Pallas's sand grouse, after intervals sometimes of many years, or sometimes for two or three years in succession. The waxwing will overspread western Europe in winter for a short time. It appears to be equally inconstant in its choice of summer quarters, as was shown by J. Wolley in Lapland. The rose pastor regularly winters in India, but never remains to breed. For this purpose the whole race seems to collect and travel northwest, but rarely, or after intervals of many years, returns to the same quarters. Verona, Broussa, Smyrna, Odessa, the Dobrudscha have all during the last half century been visited for one summer by tens of thousands, who are attracted by the visitations of locusts, on which they feed, rear their young, and go. These irruptions, however, can not be classed under the laws of ordinary migration. Not less inexplicable are such migrations as those of the African darter, which, though never yet observed to the north of the African lakes, contrives to pass, every spring, unobserved to the lake of Antioch in North Syria, where I found a large colony rearing their young, which, so soon as their progeny was able to fly, disappeared to the southeast as suddenly as they had arrived.

There is one possible explanation of the sense of direction unconsciously exercised, which I submit as a working hypothesis. We are all aware of the instinct, strong both in mammals and birds without exception, which attracts them to the place of their nativity. When the increasing cold of the northern regions, in which they all had their origin, drove the mammals southward, they could not retrace their steps, because the increasing polar sea, as the Arctic continent sank, barred their way. The birds reluctantly left their homes as winter came on, and followed the supply of food. But as the season in their

new residence became hotter in summer, they instinctively returned to their birthplaces, and there reared their young, retiring with them when the recurring winter impelled them to seek a warmer climate. Those species which, unfitted for a greater amount of heat by their more protracted sojourn in the northern regions, persisted in re-visiting their ancestral homes, or getting as near to them as they could, retained a capacity for enjoying a temperate climate, which, very gradually, was lost by the species which settled down more permanently in their new quarters, and thus a law of migration became established on the one side, and sedentary habits on the other.

MIMICRY.

If there be one question on which the field naturalist may contribute—as lion's provider to the philosopher more than another, it is on the now much disputed topic of "mimicry," whether protective or aggressive. As Mr. Beddard has remarked on this subject, "The field of hypothesis has no limits, and what we need is more study"—and, may we not add, more accurate observation of facts. The theory of protective mimicry was first propounded by Mr. H. W. Bates, from his observations on the Amazon. He found that the group of butterflies, *Heliconiidæ*, conspicuously banded with yellow and black, were provided with certain glands which secrete a nauseating fluid, supposed to render them unpalatable to birds. In the sand districts he found also similarly colored butterflies, belonging to the family *Pieridæ*, which so closely resembled the others in shape and markings as to be easily mistaken for them, but which, unprovided with such secreting glands, were unprotected from the attacks of birds. The resemblance, he thought, was brought about by natural selection for the protection of the edible butterflies, through the birds mistaking them for the inedible kind. Other cases of mimicry among a great variety of insects have since been pointed out, and the theory of protective mimicry has gained many adherents. Among birds, many instances have been adduced. Mr. Wallace has described the extraordinary similarity between birds of very different families, *Oriolus bouruensis* and *Philemon moluccensis*, both peculiar to the island of Bouru. Mr. H. O. Forbes has discovered a similar brown oriole, *Oriolus decipiens*, as closely imitating the appearance of the *Philemon timorlaœnsis* of Timor-laut. A similar instance occurs in Ceram. But Mr. Wallace observes that, while usually the mimicking species is less numerous than the mimicked, the contrary appears to be the case in Bouru, and it is difficult to see what advantage has been gained by the mimicry. Now, all the species of *Philemon* are remarkably somber colored birds, and the mimicry can not be on their side. But there are other brown orioles, more closely resembling those named, in other Moluccan islands, and yet having no resemblance to the *Philemon* of the same island, as may be seen in the case of the *Oriolus phæochromus* and *Philemon gilolensis*

from Gilolo. Yet the oriole has adopted the same livery which elsewhere is a perfect mimicry. May it not therefore be that we have, in this group of brown orioles, the original type of the family undifferentiated? As they spread east and south we may trace the gradation, through the brown striation of the New Guinea bird to the brighter, green-tinged form of the West Australian and the green plumage of the Southern Australian, while westward the brilliant yellows of the numerous Indian and African species were developed, and another group, preferring high elevations, passing through the mountain ranges of Gava, Sumatra, and Borneo, intensified the aboriginal brown into black, and hence were evolved the deep reds of the various species which culminate in the crimson of Formosa, *Oriolus ardens*, and the still deeper crimsons of *O. trailli* of the Himalayas.

It is possible that there may be similarity without mimicry, and, by the five laws of mimicry as laid down by Wallace, very many suggested cases must be eliminated. We all know that it is quite possible to find between species of very different genera extraordinary similarity which is not mimetic. Take, for instance, the remarkable identity of coloration in the case of some of the African species *Macronyx* and the American *Sturnella*, or, again, of some of the African *Campophaga* and the American *Agelæus*. The outward resemblance occurs in both cases in the red as well as in the yellow-colored species of all four groups. But we find that the *Macronyx* of America and the *Campophaga* of Africa, in acquiring this coloration, have departed widely from the plain color found in their immediate relatives. If we applied Mr. Scudder's theory on insects, we must imagine that the prototype form has become extinct, while the mimicker has established its position. This is an hypothesis which is easier to suggest than either to prove or to disprove. Similar cases may frequently be found in botany. The strawberry is not indigenous in Japan, but in the mountains there I found a potentilla in fruit which absolutely mimicked the Alpine strawberry in the minutest particulars, in its runners, its blossoms, and fruit; but the fruit was simply dry pith, supporting the seeds and retaining its color without shrinking or falling from the stalks for weeks—a remarkable case, we can not say of unconscious mimicry, but of unconscious resemblance. Mimicry in birds is comparatively rare, and still rarer in mammals, which is not surprising when we consider how small is the total number of the mammalia, and even of birds, compared with the countless species of invertebrates. Out of the vast assemblage of insects, with their varied colors and patterns, it would be strange if there were not many cases of accidental resemblance. A strict application of Wallace's five laws would perhaps, if all the circumstances were known, eliminate many accepted instances.

As to cases of edible insects mimicking inedible, Mr. Poulton admits that even unpalatable animals have their special enemies, and that the enemies of palatable animals are not indefinitely numerous.

Mr. Beddard gives tables of the results obtained by Weismann, Poulton, and others, which show that it is impossible to lay down any definite law upon the subject, and that the likes and dislikes of insect-eating animals are purely relative.

One of the most interesting cases of mimicry is that of the *Volucella*, a genus of *Diptera*, whose larvæ live on the larvæ of *Hymenoptera*, and of which the perfect insect closely resembles some species of humble-bee. Though this fact is unquestioned, yet it has recently given rise to a controversy, which, so far as one who has no claim to be an entomologist can judge, proves that while there is much that can be explained by mimicry, there is, nevertheless, a danger of its advocates pressing it too far. *Volucella bombylans* occurs in two varieties, which prey upon the humble-bees, *Bombus muscorum* and *B. lapidarius*, which they respectively resemble. Mr. Bateson does not question the behavior of the *Volucella*, but states that neither variety specially represents *B. muscorum*, and yet that they deposit their eggs more frequently in their nests than in the nests of other species which they resemble more closely. He also states that in a show case in the Royal College of Surgeons, to illustrate mining, two specimens of another species, *B. sylvarum*, were placed alongside of the *Volucella*, which they do resemble, but were labeled *B. muscorum*.

But Mr. Hart explains the parasitism in another way. He states that a nest of *B. muscorum* is made on the surface, without much attempt at concealment, and that the bee is a peculiarly gentle species, with a very feeble sting; but that the species which the *Volucella* most resemble are irascible, and therefore more dangerous to intruders. If this be so, it is difficult to see why the *Volucella* should mimic the bee, which it does not affect, more closely than the one which is generally its victim. I do not presume to express any opinion further than this, that the instances I have cited show that there is much reason for further careful observation by the field naturalist, and much yet to be discovered by the physiologist and the chemist, as to the composition and nature of animal pigments.

HEREDITARY ACQUISITIONS.

I had proposed to occupy a considerable portion of my address with a statement of the present position of the controversy on heredity, by far the most difficult and important of all those subjects which at present attract the attention of the biologist; but an attack of illness has compelled me to abandon my purpose. Not that I proposed to venture to express any opinions of my own, for with such protagonists in the field as Weisman, Wallace, Romanes, and Poulton on the one side, and Herbert Spencer and Hartog on the other, "*Non nostrum inter vos tantas componere lites.*"

So far as I can understand Weisman's theory, he assumes the separation of germ cells and somatic cells, and that each germ cell contains

in its nucleus a number of "ids," each "id" representing the personality of an ancestral member of the species, or of an antecedent species. "The first multicellular organism was probably a cluster of similar cells, but these units soon lost their original homogeneity. As the result of mere relative position, some of the cells were especially fitted to provide for the nutrition of the colony, while others undertook the work of reproduction." The latter, or germ-plasm, he assumes to possess an unlimited power of continuance, and that life is endowed with a fixed duration, not because it is contrary to its nature to be unlimited, but because the unlimited existence of individuals would be a luxury without any corresponding advantage.

Herbert Spencer remarks upon this: "The changes of every aggregate, no matter of what kind, inevitably end in a state of equilibrium. Suns and planets die, as well as organisms." But has the theory been proved, either by the histologist, the microscopist, or the chemist? Spencer presses the point that the immortality of the protozoa has not been proved. And, after all, when Weismann makes a continuity of the germ plasm the foundation of a theory of heredity, he is building upon a pure hypothesis.

From the continuity of the germ-plasm, and its relative segregation from the body at large, save with respect to nutrition, he deduces, *a priori*, the impossibility of characters acquired by the body being transmitted through the germ-plasm to the offspring. From this he implies that where we find no intelligible mechanism to convey an imprint from the body to the germ, there no imprint can be conveyed. Romanes has brought forward many instances which seem to contradict this theory, and Herbert Spencer remarks that "a recognized principle of reasoning—'the law of parsimony'—forbids the assumption of more causes than are needful for the explanation of phenomena. We have evident causes which arrest the cell multiplication; therefore it is illegitimate to ascribe this arrest to some property inherent in the cells."

With regard to the reduction or disappearance of an organ, he states "that when natural selection, either direct or reversed, is set aside, why the mere cessation of selection should cause decrease of an organ, irrespective of the direct effects of disease, I am unable to see. Beyond the production of changes in the size of parts, by the selection of fortuitously arising variation, I can see but one other cause for the production of them—the competition among the parts for nutriment. - - - The active parts are well supplied, while the inactive parts are ill supplied and dwindle, as does the arm of the Hindu fakir. This competition is the cause of economy of growth—this is the cause of decrease from disease."

I may illustrate Mr. Herbert Spencer's remarks by the familiar instance of the pinions of the Kakapo (*Stringops*)—still remaining, but powerless for flight.

As for acquired habits, such as the modification of bird architecture

by the same species under changed circumstances, how they can be better accounted for than by hereditary transmitted instinct, I do not see. I mean such cases as the ground-nesting *Didunculus* in Samoa having saved itself from extinction, since the introduction of cats, by roosting and nesting in trees; or the extraordinary acquired habit of the blackcap in the Canaries, observed by Dr. Lowe, of piercing the calyx of *Hibiscus rosasinensis*—an introduced plant—to attract insects, for which he quietly sits waiting. So the lying low of a covey of partridges under an artificial kite would seem to be a transmitted instinct from a far-off ancestry not yet lost; for many generations of partridges, I fear, must have passed since the last kite hovered over the forefathers of an English partridge, save in very few parts of the island.

I can not conclude without recalling that the past year has witnessed the severance of the last link with the pre-Darwinian naturalists in the death of Sir Richard Owen. Though never himself a field-worker or the discoverer of a single animal living or extinct, his career extends over the whole history of palaeontology. I say palaeontology, for he was not a geologist in the sense of studying the order, succession, area, structure, and disturbance of strata. But he accumulated facts on the fossil remains that came to his hands, till he won the fame of being the greatest comparative anatomist of the age. To him we owe the building up of the skeletons of the giant *Dinornithidæ* and many other of the perished forms of the gigantic sloths, armadillos, and mastodons of South America, Australia, and Europe. He was himself a colossal worker, and he never worked for popularity. He had lived and worked too long before the Victorian age to accept readily the doctrines which have revolutionized that science, though none has had a larger share in accumulating the facts, the combination of which of necessity produced that transformation. But, though he clung fondly to his old idea of the archetype, no man did more than Owen to explode the rival theories of both Wernerians and Huttonians, till the controversies of Plutonians and Neptunians came to us from the far past with as little to move our interest as the blue and green controversies of Constantinople.

Nor can we forget that it is to Sir Richard's indomitable perseverance that we owe the magnificent palace which contains the national collections, in Cromwell Road. For many years he fought the battle almost alone. His demand for a building of two stories, covering 5 acres, was denounced as audacious. The scheme was pronounced foolish, crazy, and extravagant; but, after twenty years' struggle, he was victorious, and in 1872 the act was passed which gave not 5, but more than 7 acres for the purpose. Owen retired from its direction in 1883, having achieved the crowning victory of his life. Looking back in his old age on the scientific achievements of the past, he fully recognized the prospects of still further advances, and observed, "The known is very small

compared with the knowable, and we may trust in the Author of all truth, who, I think, will not let that truth remain forever hidden."

I have endeavored to show that there is still room for all workers, that the naturalist has his place, though the morphologist and the physiologist have rightly come into far greater prominence, and we need not yet abandon the field glass and the lens for the microscope and the scalpel. The studies of the laboratory still leave room for the observations of the field. The investigation of muscles, the analysis of brain tissue, the research into the chemical properties of pigment, have not rendered worthless the study and observation of life and habits. As you can not diagnose the red Indian and the Anglo-Saxon by a comparison of their respective skeletons or researches into their muscular structure, but require to know the habits, the language, the modes of thought of each; so the mammal, the bird, and even the invertebrate, has his character, his voice, his impulses, aye, I will add, his ideas, to be taken into account in order to discriminate him. There is something beyond matter in life, even in its lowest forms. I may quote on this the caution uttered by a predecessor of mine in this chair (Prof. Milnes Marshall): "One thing above all is apparent, that embryologists must not work single-handed; must not be satisfied with an acquaintance, however exact, with animals from the side of development only; for embryos have this in common with maps, that too close and too exclusive a study of them is apt to disturb a man's reasoning power."

The ancient Greek philosopher gives us a threefold division of the intellectual faculties—*φρόνησις*, *ἐπιστήμη*, *σύνεσις*—and I think we may apply it to the subdivision of labor in natural science: *φρόνησις*, *ἡ τὰ καθ' ἕκαστα γνωρίζουσα*, is the power that divides, discerns, distinguishes—*i. e.*, the naturalist; *σύνεσις*, the operation of the closest zoologist, who investigates and experiments; and *ἐπιστήμη*, the faculty of the philosopher, who draws his conclusions from facts and observations.

The older naturalists lost much from lack of the records of previous observations; their difficulties were not ours, but they went to nature for their teachings rather than to books. Now we find it hard to avoid being smothered with the literature on the subject, and being choked with the dust of libraries. The danger against which Prof. Marshall warns the embryologist is not confined to him alone; the observer of facts is equally exposed to it, and he must beware of the danger, else he may become a mere materialist. The poetic, the imaginative, the emotional, the spiritual, all go to make up the man; and if one of these is missing, he is incomplete.

I can not but feel that the danger of this concentration upon one side only of nature is painfully illustrated in the life of our great master, Darwin. In his early days he was a lover of literature, he delighted in Shakespeare and other poets; but after years of scientific activity and interest, he found on taking them up again that he had not only grown indifferent to them, but that they were even distasteful to him. He

had suffered a sort of atrophy on that side of his nature, as the disused pinions of the Kakapo have become powerless,—the spiritual, the imaginative, the emotional, we may call it.

The case of Darwin illustrates a law—a principle we may call it—namely, that the spiritual faculty lives or dies by exercise or the want of it even as does the bodily. Yet the atrophy was unconscious. Far was it from Darwin to ignore or depreciate studies not his own. He has shown us this when he prefixed to the title-page of his great work the following extract from Lord Chancellor Bacon: "To conclude, therefore, let no man, out of a weak conceit of sobriety, or an ill-applied moderation, think or maintain that a man can search too far, or be too well studied in the book of God's word, or in the book of God's works, divinity or philosophy, but rather let men endeavor an endless progress or proficience in both." In true harmony this with the spirit of the father of natural history, concluding with the words, "O Lord, how manifold are Thy works, in wisdom hast Thou made them all, the earth is full of Thy riches."

THE SO-CALLED BUGONIA OF THE ANCIENTS,

AND ITS RELATION TO A BEE-LIKE FLY,—ERISTALIS TENAX.*

By C. R. Osten Sacken.

For more than two thousand years a superstition has been prevalent in the minds of the masses, as well as in books, to the effect that, besides the usual production of honey bees in hives, they originated by spontaneous generation from carcasses of dead animals, and principally from those of oxen. Thus arose in Greece the term *Bugonia* (from βους an ox, and γονή, progeny), as well as the expression *bugenes melissae*, *taurigenæ apes*, that is, oxen-born bees, in the Greek and Latin literature. This superstition prevailed also in northern Africa and in some parts of Asia; it continued through the Middle Ages, and found expression even in the sixteenth and seventeenth centuries. The friend of Luther, the learned and pious Melanchthon, considered it as a divine provision; an Italian poet of the sixteenth century put it into verse;† the great naturalist Aldrovandi (1602) accepted it without contradiction; the English naturalist Moufet (Theatren Insectorum, 1634)‡ spoke of it as a common occurrence (*experientia rustica et vulgaris*, *l. c.*, p. 12); and, finally, the learned Bochart (1663) § admitted it as an undoubted truth.

* Extracts from article in *Bulletino della Societa Entomologica Italiana*, 1893.

† Giovanni Rucellai (1475–1525), in Florence and Rome, died as Governer of S. Angelo. His poem: *Le Api*, Amsterd. latin edit. 1681, p. 68, contains an account of the *Bugonia*.

‡ Moufet was a contemporary of Queen Elizabeth, and died without publishing his work. "It fell into the hands of Sir Theod. Mayerne, Baron d'Aubone, one of the court physicians in the time of Charles I, who at length published it, prefixing a dedication to Sir Wm. Paddy, M. D., in 1634." (This passage, as well as the previous history of the "Theatrum Insectorum," will be found in Kirby and Spence, Introd. IV, p. 429–430.) I spell *Moufet* (K. and S. have *Mouffet*) as I find it on the title-page of my copy of the "Theatrum," 1634. By a strange and perhaps significant coincidence, such works as Moufet's, Swammerdam's, and Lyonet's "Recherches," were neglected by their contemporaries, and published long after the death of their authors.

§ Samuel Bochart, Hierozoicon, *sive opus bipartitum de animalibus sacræ scripturæ*, London, 1663. This stupendous monument of erudition was my principal source for all the references on the *Bugonia* from Greek and Roman authors (*l. c.* vol. II, p. 502–505). I have also used Aldrovandi, *De animalibus insectis*, Bologna, 1602 (pp. 8–60.

The original cause of this delusion lies in the fact that a very common fly, scientifically called *Eristalis tenax* (popularly the drone fly), lays its eggs upon carcasses of animals, that its larvæ develop within the putrescent mass, and finally change into a swarm of flies which, in their shape, hairy clothing and color, look exactly like bees, although they belong to a totally different order of insects. Bees belong to the Order *Hymenoptera*, and have four wings; the female is provided with a sting at the end of the body; the fly *Eristalis* belongs to the Order *Diptera*, has only two wings and no sting.

The final extinction of this absurd notion among civilized nations was due to two causes:

(1) Among scientific men, to the confutation of the old belief in spontaneous generation, and the general recognition of the principle: *omne virum ex ovo*, proclaimed by William Harvey (1651), and by the great Italian naturalist, Redi (1668).*

(2) Among the ignorant crowd, to the introduction of a sanitary police, which prevents carcasses from lying about and affording the spectacle of bee-like flies swarming around them.

Modern commentators of Greek and Latin authors have treated the *Bugonia* with a contemptuous sneer,† without taking into consideration that a superstition so universal and so persistent can not be dismissed so easily, and must necessarily have some foundation in fact. The refutation of an error is not complete until the source of the error is revealed. In a short paper on the geographical distribution of the fly, *Eristalis tenex* (Entom. M. Mag., XXIII, p. 97–99, London, 1886), I introduced incidentally the explanation of the *Bugonia*, founded upon a resemblance of this fly to the honey-bee. Already at that time it seemed strange to me that such an obvious and simple explanation had never been proposed before. Since then I have undertaken a regular search in entomological literature in order to ascertain if any approach to such a solution could be found in previous writers, and to inquire into the causes that had delayed it so long. I shall now attempt to give an account of my inquiry and to show that, as soon as certain conditions, necessary for the confutation of that error were fulfilled, the error disappeared of itself.

The principal factor underlying the whole intellectual phenomenon

*Francesco Redi's work, *Esperienze intorno alla generazione degl'insetti*, appeared in Florence, 1668. F. Redi, born in Arezzo, 1626; died in Pisa, 1697. He was the physician of the Grand Duke of Tuscany, and at the same time a naturalist, a poet and a literary personage in general. His letters are charming. I possess a Neapolitan edition of his complete works in seven volumes, dated 1778, and shall quote from it.

†For instance, Joh. Beckmann, commentator of Antigonus Caristius, Joh. H. Voss, translator and commentator of the Georgics, etc. I owe my acquaintance with these books to Prof. Zangemeister, director of the University Library in Heidelberg. The commentaries of Prof. Martyn on the Georgica (London, 1741), which I find quoted in Smith's Diction. Biogr. and Mythol., etc., I have not been able to consult.

we are inquiring into is the well-known influence which prevails in all human matters, and this factor is *routine.*

"Thinking is difficult, and acting according to reason is irksome,"* said Goethe. People see, and believe in what they see, and the belief easily becomes a tradition. It may be asked, If those people had that belief, why did they not try to verify it by experiment, the more so as an economical interest seemed to be connected with it.

The answer is that they probably did try the experiment, and did obtain something that looked like a bee; but that there was a second part of the experiment, which, if they ever tried it, never succeeded, and that was to make the bee-like *something* produce honey. If they did not care much about this failure, and did not prosecute the experiment any further, it is probably because, in most cases, they found that it was much easier to procure bees in the ordinary way. That such was really the kind of reasoning which prevailed in those times clearly results from the collation of the passages of ancient authors about the *Bugonia.* There were different *recipes* for it; one wanted the ox to be buried with projecting horns, through which, after they were cut off, bees would emerge; another (and no less a personage than Pliny), contended that it is sufficient to use the entrails of an ox, and to cover them with dung, etc. Florentinus, an obscure writer in the Geoponica† gives an account of the process that was used by Juba, King of Mauritania: "Build a house, 10 cubits high, with all the sides of equal dimensions, with one door, and four windows, one on each side; put an ox into it, thirty months old, very fat and fleshy; let a number of young men kill him by beating him violently with clubs, so as to mangle both flesh and bones, but taking care not to shed any blood; let all the orifices, mouth, eyes, nose, etc., be stopped up with clean and fine linen, impregnated with pitch; let a quantity of thyme be strewed under the reclining animal, and then let windows and doors be closed and covered with a thick coating of clay, to prevent the access of air or wind. Three weeks later let the house be opened, and let light and fresh air get access to it, except from the

* "Denken ist schwer, nach dem Gedachten handeln unbequem." Goethe.

†The *Geoponica,* or Work of Agriculture, was a compilation of old Greek and Roman authors on the same subject, ordered by the Emperor Constantine Porphyrogeneta, and executed in all probability by Cassianus Bassus, a contemporary writer (I quote from W. Smith, Dict. of Gr. and Rom. Biogr. and Mythol., *sub voce* Bassus). Florentinus, to all appearances, is one of the authors made use of in the *Geoponica,* but nothing more seems to be known about him (compare *l. c. sub voce* Florentinus; the statement of this article, by a different author, is not in entire agreement with that on Bassus.)—Prof. A. Merx, of Heidelberg, the celebrated Syriac scholar, told me of an old Syriac translation of the *Geoponica,* which may possibly have been the channel through which the nation of the *Bugonia* spread eastwards. He added that the Hayât el-haiwân (the Life of Animals) by *Damiri* (or Demiri), and other Arabic works, may contain allusions to the *Bugonia.* It is beyond my province to follow up these suggestions, but I take advantage of this opportunity to express to Prof. Merx my sincere thanks for the interest he took in my research.

side from which the wind blows strongest. After eleven days you will find the house full of bees, hanging together in clusters, and nothing left of the ox but horns, bones, and hair." (Aldrovandi, *l. c.* p. 58; also a mention in Redi, *l. c.* I, p. 53.) Some authors, like Celus, and afterwards Columella, show their common sense in declaring that is useless to take all this trouble, when hive-born bees can be so easily obtained. I shall return to this subject in treating of the literature of the *Bugonia*.

All these errors would have been avoided if the people from the very beginning, had known how to distinguish a honey-bee from a bee-like fly. Until this knowledge was forthcoming there was no reason for not believing in the *Bugonia*.

Aristotle* knew that four-winged insects have the sting in the tail and the two-winged ones in the front of the head; and for this reason, if he ever came in contact with *Eristalis tenax*, he would have recognized a fly, and not a bee, in it. At any rate, although he was a believer in spontaneous generation, he never mentioned the *Bugonia* in his paragraphs about bees.

But after Aristotle, for a period of about twenty centuries, the question of *Bugonia* remained in abeyance, and the belief was accepted even by men of learning. I will show in the sequel that, as late as 1662, there was a Dutch *savant*, in whose presence an *E. tenax* was produced from putrescent matter, and who actually took it for a honey-bee, and the case before him as an instance of *Bugonia!*

The thesis which I maintain is, that it is to *E. tenax* alone, and no other bee-like or wasp-like flies (*Œstridæ*, *Helophilus*, etc.) that the origin of the belief in the *Bugonia* is due; in other words, that if this particular fly had not existed the belief would never have arisen. *E. tenax* has several attributes which make it pre-eminently fitted for assuming the rôle of an oxen-born bee:

(1) It is more like a honey-bee than any other fly; the other flies, which have been named in connection with the *Bugonia*, have a different aspect; the *Œstridæ* are more like humble-bees; *Helophilus* is more like a wasp.

(2) It oviposits on carcasses in a state of far advanced decomposition in which its larvæ thrive, and these habits correspond to the tradition of the oxen-born bee. The larvæ of Œstrus (genus *Hypoderma*) live in the skin of *living* animals; the wasp-like *Helophilus*, although a close relative of *Eristalis* in the zoological system, and developing, like that

* Aristoteles, *Hist. Anim.* IV, 7, 4: "The winged ones among insects, are either two-winged, like flies, or four-winged, like bees; but none of those which have a sting in the tail are two-winged." And *l. c.* IV, 7, 3: "Also the *myops* (probably *Hæmatopota cæcutiens*) and the *œstrus* (Tabanus) have a hard tongue - - - because all that have no tail sting use the tongue as a weapon." Also in the *De partibus anim.* IV, 6, 3–4, where Aristoteles says that Diptera have but two wings, because they are lighter than Hymenoptera. I. B. Meyer, *Aristoteles Thierkunde*, Berlin, 1855, p. 209, has some critical remarks about these passages.

fly, from a rat-tailed larva, is, in comparison to *E. tenax*, of rather rare occurrence, and would not have been noticed so easily and so generally.

(3) The very common occurrence of *Eristalis tenax*, and (as I will show in the paragraph about its geographical distribution) the truly fabulous rapidity of its propagation under favorable circumstances, must have struck, from the earliest times, the eyes and the imagination of the ignorant crowd, and this obtrusiveness, combined with the swarming of the fly round carcasses, and its bee-like aspect led quite naturally towards the belief in the *Bugonia*.

This thesis, that *Eristalis tenax* alone is the cause of the *Bugonia* craze, being given, what remains for me to do is to show how, at the end of those twenty centuries of inertia, the question about the *Bugonia* came up again, and after some uncertainty and groping, found its solution in the recognition of that truth.

A group of men, almost contemporaries, brought about that solution in the seventeenth century, by dint of observing insects in life, and not by merely compiling authorities. These men were: Goedart (1620–1668), Blankaart (his work appeared in 1688), Swammerdam (1637–1680), all three in Holland; Redi (1626–1697) and Vallisnieri (1661–1730) in Italy, and finally Réaumur (1683–1757) in France.

Goedart (*Metamorphosis insectorum*, etc., 1662; edition in Dutch 1669) gives rough but distinct figures of the larva, pupa, and imago of *E. tenax* (*l. c.*, Tab. II, p. 25). He calls the larva *vermiculus porcinus*. The imago is distinctly figured as a two-winged fly, and the letterpress also speaks of two wings; nevertheless, for some unknown reason, Goedart calls it *apis* (bee).

That so careful and conscientious an observer should have taken a fly for a bee is out of the question. Swammerdam, who reproached him with this mistake (*Bibl. Nat. Germ.*, ed. 1758, p. 212), changed his mind in another part of his work (*l. c.*, p. 257), and took to task Dr. de Mey, Goedart's commentator, as the guilty party. Goedart was not a classical scholar; Réaumur (vol. I, p. 29) notices it in a passage, which is a choice specimen of French *finesse* and urbanity: "Ceux même (les naturalistes) qui, par une ignorance peut-être heureuse, n'étaient pas en état de lire les anciens, comme Goedart et Mlle. Mérian, ont travaillè utilement." It was the classically learned de Mey who saw in Goedart's observation an actual case of *Bugonia*. He took the *Eristalis* for a honey-bee, and composed a preposterous *Annotation* about it. Swammerdam, the representative of the new science, was seized with an almost ludicrous fit of wrath about this piece of presumption. "The fuss, says he (*l. c.*) de Mey makes about this story is truly astonishing, and plainly shows that he is equally ignorant of the nature of the bee, as of the nature of the fly. This is one of the bad habits of our day that statements are made on matters about which one knows nothing, for the mere purpose of getting a reputation of wisdom and knowledge." An amusing instance of the collision between the old and the new learning.

Blankaart (*Schauplatz der Raupen, Wurmer*, etc.; Dutch edit., 1688; German edit., 1690) describes and figures the larva, pupa, and imago of *E. tenax*. The larva he calls (after Goedart) *Schwein-Made*. Of the imago, he says, "eine Art von zahmen Bienen (*Musca apiformis*) mit zwei Flügeln," etc. ("A kind of tame bees with wings".) He adds: "Quite different from what Goedart taught us," a reproach which, I have shown, is undeserved.

Swammerdam's (1637–1680) principal work, the "Biblia naturæ" (Leyden, 1737–38; in German, Leipzig, 1858), was published more than half a century after his death.

Swammerdam, in two passages of his "Biblia," comes very near connecting *Eristalis tenax* with the *Bugonia*, and it is only his bias for a literary interpretation of a scriptural text which prevents him from taking the last step that was needed. In his chapter on bees (pp. 210–212) he says that because bees are cleanly animals, and never alight on carcasses, the story of Samson has appeared to many strange and incredible. He offers an explanation very similar to that of Bochart* (whom he does not quote and does not seem to know), that the lion was not a corpse, but a skeleton. It was in the height of summer; the larvæ of certain flies always occurring in carcasses have, in a very short time, devoured all the flesh; the remaining skeleton was soon freed from all bad smells by the combined action of sun, rain, and dew; under such circumstances it is possible ("es lässt sich ohnschwer begreifen") that the skeleton may have become the habitation of bees during the swarming season (*l. c.*, p. 211, right column). On page 212, Swammerdam continues: "This story of Samson and his bees, misunderstood as it was, has undoubtedly given rise to the common ignorant craze that bees originate from lions, oxen, and horses. The craze was probably confirmed by the sight of the great mass of worms which occur in such carcasses in summer, the more so as these worms are somewhat ("einigermassen") like the larvæ of bees. This apparent resemblance has undoubtedly fortified this error, which, ridiculous and groundless as it is, has found advocates even among the most learned men. The laborious Goedart has not hesitated to make bees breed from dung-worms, and the learned De Mey has shared his opinion, although what he took for a bee was nothing but a fly, which looked somewhat bee-like," etc.

In a later part of this work (*l. c.*, pp. 256–257) Swammerdam gives a detailed description (with figures) of the three stages of *Eristalis tenax*. He notices (*l. c.*, p. 257 at the bottom) that the fly has been frequently taken for a bee, and that Augerius Clutius,† in his little work on bees,

* Bochart's explanation will be given further on.

† Theodor Augur Clutius, also called Dirck Cluyt, apothecary and botanist in Leyden, at the end of the sixteenth and the beginning of the next century. His book: On Bees (Vande Bien, etc.), appeared in Leyden in 1597 and had seven editions, the last in 1705. I borrow these statements from H. A. Hagen's Bibliotheca

has denounced this error. He exonerates Goedart of his supposed mistake and charges De Mey with it (as I have already explained above).

It follows from these statements that Swammerdam was fully aware of the absurdity of the *Bugonia* craze, but that he did not quite grasp the part played by *E. tenax* in it, and would not, even in the presence of sufficient evidence, give up his basis for a literal interpretation of the Holy Scriptures. In fact he connects the belief in the *Bugonia* with the story of the bees of Samson, as if the ancients (Greeks and Romans) knew anything about Samson!

Redi, a contemporary of Swammerdam, stood on the same level with him on the question of the *Bugonia*. Both were adversaries of spontaneous generation, and nevertheless both misunderstood the story of Samson. Redi (*Esperienze*, etc., p. 58) accepts the interpretation of Bochart. And with regard to the relation of bee-like flies, and especially of *E. tenax* to the *Bugonia*, both seem to have been in the dark. My Neapolitan edition of Redi (1778) contains a supplement by Girolamo Gaspari* from Verona (*l. c.*, *p.* 149), who states quite distinctly that Redi only denounced the error, and that it was *Vallisnieri* who explained its origin by discovering certain bee-like flies which insert their eggs into the skins of animals. But this discovery of Vallisnieri was not quite up to the mark; what he discovered were *Oestridæ* of the genus *Hypoderma*, and not *E. tenax*. Hypodermæ are bot flies, some of which look more like humblebees than honeybees; their larvæ occur in the skin of oxen and of different kinds of deer, including reindeer. Vallisnieri was also mistaken when he took the bot of the horse (*Gastrus equi*), whose larva lives in the stomach of this animal, for the representative of the wasp, which the ancient writers thought was generated from carcasses of horses. It is a fly of the genus *Helophilus*, which passed for a wasp among the ancients; *Helophilus* is a close relative of *Eristalis;* it has, like *Eristalis*, a rat-tailed larva, which live in putrescent matter. But in its coloring *Helophilus* resembles a wasp (black, with yellow stripes and spots), while *Eristalis* resembles a bee. And yet that Vallisnieri knew *E. tenax* may be inferred from his words: "That stout and stupid fly, which is bred from certain worms, provided with a tail, and sometimes called *aquatic intestines* (*intestini aquatici*)" (Vallisnieri *Esperienze*, etc., p., 149). On the same page Vallisnieri gives instances of the confusion between the terms of *bees* and *flies* in ancient authors, and quotes, among others, Lampridius *Life of Heliogabalus*, chap. 26. I

entomologica, I, p. 133. I have consulted the fifth edition (1648 which was kindly lent to me by the Grand Ducal Library in Carlsruhe. Clutius also speaks of the *Oestridæ* (p. 10). The "Augerius" (misprinted *Augenius*) referred to by Vallisnieri, *Esperienze*, etc., p. 14 (1726), is evidently the same Clutius.

* Dr. G. Gaspari (*l. c.*) quotes from Vallisnieri's *Dialogo fra 'l Malpighi, e Plinio*, Venezia, 1700. I have not seen this work, but I possess his, *Esperienze ed Osservazioni*, etc., second edition, 1726. Antonio Vallisnieri (1661–1730) was professor in Padua.

translate this passage of Lampridius: "As a gift to his parasites, Heliogabalus oftentimes sent them vessels filled with frogs, scorpions, snakes, and other disgusting animals. Such were sometimes filled with numerous flies, which he called *tame bees*." These tame bees were undoubtedly *Eristalis tenax*, and the practical joke of the Roman Emperor consisted in frightening his friends with them.

Reaumur (*Mem.*, vol. IV, 439, quarto edit, 1738) came a little later than the above-quoted authors and made use of their works. (Compare vol I, p. 29, and vol. IV, p. 519, about Vallisnieri.) It is Reaumur who, for the first time, brought the *Bugonia* and *E. tenax* distinctly together. At the very beginning of the chapter, "Of two-winged flies which look like bees," in which he gives the life history of this fly, the following passage occurs: "Such resemblances (between certain hymenoptera and diptera) have deceived people at a time when observations were not very accurate; such resemblances have made people believe that honey-bees, humble-bees, hornets, and wasps originate in putrescent matter upon which those other flies occur." ("Ce sont ces memes ressemblances qui en ont imposé dans des temps ou l'on n'y regardait pas d'assez près; ce sont ces ressemblances qui ont fait croire que les abeilles, que les bourdons, que les frelons et les guepés venaient de certaines matières pourries sur lesquelles on trouvait les autres mouches.") This is the explanation of the Bugonia in a nutshell.

But Reaumur was working at a time when a systematic nomenclature of entomology was not yet introduced, and that prevented him from expressing his meaning with more precision; in other words, from *naming* the species which he meant. Thus it happened that the very important, but perhaps too concise passage which I quote has ever since been entirely overlooked, as if it had never existed. I have searched in vain in Kirby and Spence, in Westwood's Introduction,* and in other entomological works for any other passage, either alluding to Reaumur or offering an independent explanation of the origin of the *Bugonia*.

This apparent missing link in entomological literature encourages me to put the whole case before the public, although I feel very unequal to the task, especially in its philological and literary aspect. I consider the story of the *Bugonia* principally as an interesting episode in the history of science; a remarkable instance of the tenacity of ignorance and of the insufficiency of the testimony of the senses alone, without the control of previously acquired knowledge.

The origin of the belief in the *Bugonia* must be sought in pre-historic times, when country people, keeping cattle and bees, observed bee-like flies swarming about dead animals. The earliest appearance of the

*The passage in *Westwood*, Introd., II, p. 557: "Many species so much resemble humble-bees, wasps, and other diptera that they are constantly mistaken for them by the inexperienced," contains no reference whatever to the *Bugonia*.

belief in literature is found in the story of Samson (*Judges*, XIV, 8), of which I have already spoken in the paragraph about Swammerdam. In the vineyards of Timnah Samson had killed a lion, and "after awhile," on his way to fetch his bride, "he turned aside to see the carcass of the lion: and behold, there was a swarm of bees in the body of the lion, and honey; and he took it into his hands, and went on, eating as he went," etc. As soon as a myth is started it begins to grow. The seeing of a swarm of bee-like flies was a fact; the finding and eating the honey was the myth grown out of the misconceived fact. The riddle, which Samson proposes afterwards, affords the proof of another fact: that the belief in the *Bugonia* was current among the people at that time; because, without that *substratum*, the riddle would not have had any meaning:

> Out of the eater came forth meat
> And out of the strong came forth sweetness.

The narrator of the tale arranges it so as to make it a preamble to the riddle: When Samson gave the honey to his parents he did not tell them that he had taken it from the body of the lion; because if he told them, they (as believers in the *Bugonia*) would have solved the riddle immediately, without the necessity of guessing. The story, therefore, represents a real occurrence, based upon a well-observed but wrongly interpreted natural phenomenon.

It is curious to notice how Samuel Boshart (vol. II, p. 502) comments on this passage of the Book of *Judges* in order to meet possible objections. He admits that bees, besides their natural origin in hives, are produced from dead oxen, in conformity to the opinion of numerous ancient authors; but he scoffs at the ignorance of those who, relying on the scriptural text, admit two kinds of animal-bred bees, and attacks especially Moufet on that matter: "Nec audiendus Mufetus Anglus qui in Insectorum Theatro, alias apes scribit esse *leontogenes*, alias *taurogenes*." In order to explain the appearance of bees in Samson's lion, Bochart establishes three propositions:

(1) Although it is stated in the text that the bees were in the carcass, it is not stated that they were *born* there ("apes in leonis corpore fuisse repertas, non tamen ibi natas").

(2) That between the killing of the lion and the finding of his remains *a whole year* had elapsed, because the expression "after a while" (*post diem*) in Hebrew must be understood to mean a whole year. A host of authorities are adduced by Bochart to sustain this strange proposition.

(3) That at the end of a year the corpse was reduced to the state of a clean skeleton, in which the bees could take shelter without repugnance, the bees being clean animals.

But Bochart does not explain how those cleanly bees which could not stand a rotten lion, could be born from rotten oxen.

All this display of learning and acute reasoning would have been unnecessary if Bochart had known that his pretended honey-bees were not bees at all, but two-winged flies. And it is interesting to notice how both Swammerdam and Bochart were led astray by their intense desire to give a literal interpretation to the scriptural text, and to save Samson's bees at any price, although their starting point was quite different, because Bochart believed in the *Bugonia* and Swammerdam did not. The former was hampered by the authority of the ancient writers, as well as by that of the Holy Scriptures; Swammerdam by the Scriptures alone.

About the time when I published my above quoted article in the *Entomological Monthly Magazine* I communicated my solution of the question of the *Bugonia*, and its possible application to the story of Samson, to the eminent professor of scriptural exegesis in Heidelberg, Dr. Adalbert Merx. At the same time I handed to him a box, containing about half a dozen of pinned specimens of *Eristalis tenax*. He received this communication with evident delight, and recognized that it offered a simple solution of a text which had been discussed for centuries. Soon afterwards, he published in the German *Protestantische Kirchenzeitung* No. 17, 1887, pp. 389–392, a learned article entitled: "Der Honig im Cadaver des Lowen" (The honey in the carcass of the lion). It contains a summary of the discussions provoked by Samson's bees, and the controversies of Alphons Tostatus, Bishop of Avila (+ 1454), of Lorinus of Avignon (1559–1634), and the Jesuit Bonfrere (1573–1643). Professor Merx concludes by accepting the resemblance of *E. tenax* to a bee as a natural solution of the question "All the persons, says he, to whom I showed the specimens of *Eristalis* at once recognized bees in them, except a medical man who had some knowledge of Entomology."*

It is now time for me to say something about *Eristalis tenax* Linné, that bee-like fly, the resemblance of which to a honey-bee, has confused the brains of the scientific and unscientific world for so many centuries. I shall give a short account of its outward appearance, its metamorphosis from the larva, and of some remarkable circumstances connected with its geographical distribution. It belongs to the large family Syrphidæ which contains a considerable number of handsomely colored flies, very fond of flowers; "they fly with amazing rapidity, and many delight to hover immovably over certain spots, to which they will return if disturbed for a considerable number of times." (Westw. Introd., II. p. 557.) Their coloring consists in many cases of yellow crossbands and spots on the abdomen, and also of similar

* John Curtis, *Brit. Ent. Diptera*, N. 432. *Eristalis nubilipennis*, says: "I have had some difficulty to convince persons totally ignorant of entomology, that the *Eristales* were not bees, and it is worthy of observation that, when resting, the *Eristalis tenax*, and probably the whole genus, heave their bodies up and down as bees do, as if they were panting."

marks on the thorax; or else they are clothed with a hairy covering of different colors.

E. tenax is of a duller coloring than most of the species of the family and, in that respect, it has remarkable resemblance to a honeybee. "This resemblance is so great (says Reaumur, IV, p. 440)* that, accustomed as I am to see bees, I hardly ever dared to take one of those flies in my hand without hesitation. - - - The colors, the size, the conformation, and the proportions of the different parts of the body of these two insects, belonging to two different orders, are very much alike. The bees have a slightly more elongated body, and their head is proportionally smaller. The fly keeps the wings more or less divaricated; on the contrary bees at rest keep them above the abdomen, the one covering them over; but in sucking flowers, or collecting wax, they often have them divaricated. Both insects frequent flowers, and behave upon them in more or less the same manner," etc.

The coloring of the abdomen of the honey bees is variable; some varieties have very distinct brownish-yellow crossbands at its base. Just the same varieties occur in the coloring of the fly *E. tenax*.

The fly appears in great abundance principally in autumn and, when the days become chilly, in a semitorpid state, either sucking flowers or crawling slowly upon walls and fences.

The larva of *E. tenax* is the well-known *rat-tailed larva* (*ver à queue de rat*, so called for the first time by Reaumur, *l. c.* IV, p. 443); it is figured in the same volume, plate XXX. A long tail, with a telescopic arrangement for prolonging or shortening it, enables the larvæ to live several inches deep in the water and to pump air from the surface. They frequent putrid waters, sewers, etc., and crawl out of them to change into pupæ in the vicinity. The vitality of these larvæ is said to be extraordinary, and for this reason Linné gave it the name *tenax* "Habitat in fimetis, cloacis, aquis putrescentibus vix prelo† destruenda larva" (Linné, *Syst. Nat.*, 12th edit., p. 984, 1766). Kirby and Spence (vol. IV, p. 189) say: "An inhabitant of muddy pools, it has occasionally been taken up with the water used in paper-making, and, strange to say, according to Linné (*Fauna Suecica*) resisted without injury to immense pressure given to the surrounding pulp; like *leather-coat Jack*, mentioned by Mr. Bell (*Anatomy of Expression in Painting*, 170), who, from a similar force of muscle, could suffer carriages to drive over him without receiving any injury." Geoffroy (vol. II, p. 521, 1762) repeats the same story: "This larva also occurs in the pulp of rags from which

*There is an evident error in Reaumur, *l. c.* in the reference to the plate XXXI, fig. 8. The true *E. tenax* is represented (rather indifferently) on Pl. XX, f. 7; compare the explanation of this figure on p. 283, Mouche en forme d'abeille, etc. Plate XXXI, f. 8, is correctly quoted, *l. c.*, p. 474, and represents *Eristalis arbustorum* ♀, or some allied species.

†Translation. "Lives in dungheaps, cesspools, putrescent waters; a roller even will not kill it."

paper is made; when this pulp is beaten for the manufacture of paper the larva although badly struck by the hammers, is not crushed, but survives and produces a fly. This fact would seem incredible, if it was not affirmed by the great naturalist."

This tenacity may have been the cause of the success of this fly in the so-called struggle for existence. It has attained an almost universal distribution, and the progress of civilization has only increased its opportunities. In ancient times it had to look out for stray carcasses; civilization offers it its drains, canalizations, cesspools, and dung-heaps, in which it can wallow in abundance, and perhaps better protected against possible enemies. Different in this from other kinds of insects, which disappear with the culture of the land, *E. tenax* thus gained a new impulse, and spread in new countries with an astounding rapidity. It entered into a kind of commensalism with man, like the *Musca domestica*, *Teichomyza fusca*, and some other dipterous insects, which are at present hardly found anywhere except among human habitations. It is very rare now to come across a carcass, and to see *E. tenax* hovering about it. The only instance I have found in the literature consulted by me concerns another species of *Eristalis*, *E. anthophorinus* Zett., and that case occurred in a distant and primitive country. Zetterstedt (*Dipt. Scand.* II, 666), being in Lapland, observed a small swarm of flies of this species round the carcass of a sheep: "Ad cadaver ovis putridissium, aquæ stagnanti maximam partem immersum, odore fœtidissimum, individua 7 vel 8 sono pipiente celerrime circumvolando congregantia, et in cadaveris parte supra aquam elevata interdum sedentia, die 16 Junii in Lapponia observavi, ova in cadavere sine dubio depositura."*

The occurrence of this fly is reported from all parts of the Old World with the exception of South Africa and the East Indies, about which I have no certain data. It occurs in the whole of Europe, as far north as Lapland, the northern and central Asia, beginning with Syria and Persia, through China to Japan; in northern Africa (Algiers) and on the islands surrounding Africa (Madeira, the Canary Islands, and, on the eastern side, Madagascar and Bourbon). During my twenty years of residence in North America, spent in collecting diptera and receiving collections from many other entomologists, I never met with a specimen of *E. tenax* until November 5, 1875, when, to my great astonishment, I found one on a window in Dr. Hagen's house in Cambridge, Mass. A year later (October–November, 1876) I observed several specimens on the fences of Newport, R. I. In June, 1877, I sailed for Europe, but I heard afterwards that during the same year the fly had

* (Translation). In Lapland, on the 16th of June, near a very putrid carcass of a sheep, the greater part of which was immersed in stagnant, most offensively smelling water, I perceived seven or eight specimens flying about rapidly and emitting a piping sound, and sometimes alighting on the portion of the carcass above the water, evidently for the purpose of depositing their eggs.

become so common that "hundreds were caught." A few years later the species was reported from nearly all the States of the Union, including California and Washington Territory; also from Canada (Montreal, common, as stated by Mr. Caulfield in *Canad. Entom.*, 1884, p. 138).

A communication made by the American dipterologist, Dr. Williston, proves that the invasion has gone, not from the Atlantic border to the West, as one might have expected, but, on the contrary, from West to East. Dr. Williston had seen a specimen of *E. tenax* hidden among a lot of duplicates in Prof. Riley's collection, bearing a label St. Louis, August, 1870. Upon drawing Prof. Riley's attention to the fly (which the latter did not previously know by name) he was assured that the species had long been familiar to Mr. Riley in outhouses about St. Louis. The surprising rapidity however with which the species spread along the Atlantic coast soon after its first appearance renders it probable that it can not have existed in St. Louis very long before 1870, otherwise it would have reached the Atlantic sooner. We are thus driven to accept the following outline of its history. We know that it exists in Japan and eastern Siberia; from there it must have migrated to the North American Pacific coast perhaps long ago. It did not spread eastward at once, because the necessary conditions for its existence were wanting on the immense plains it had to cross, just as the Colorado beetle lived in the Rocky Mountains on *Solanum rostratum*, and did not spread eastwards until civilization brought the potato plant (*Solanum tuberosum*) with it, and thus bridged over for that beetle the distance between its native mountains and the Atlantic coast. The condition which civilization brought, and which favored the rapid eastward progress of *E. tenax*, consisted in the drains, sewers, and cesspools, those necessary concomitants of crowded centers and the usual abodes of the larva of *Eristalis*.*

The immigration of *E. tenax* into New Zealand is of a still more recent date than that in North America. The Catalogues of the New Zealand Diptera, by Nowicky (1875) and Prof. J. W. Hutton (1881) do not mention it. It was first noticed in Wellington (North Island) in October and November, 1888. In June, 1890, Mr. W. W. Smith (Ashburton, South Island) writes: "It is now widely dispersed and very plentiful in the South Island." (Notes on *Eristalis tenax* in New Zealand, by W. W. Smith, in the *Entom. M. Mag.*, London, 1890, pp, 240–242.)

About Australia, with regard to *E. tenax*, I am sorry to say, I have no information whatever.

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* All the details and references about the geographical distribution of *Eristalis tenax* will be found in my two articles:

1. Facts concerning the importation or non-importation of diptera into distant countries (*Trans. Ent. Soc.*, London, 1884, pp. 489–496).

2. Some new facts concerning *Eristales tenax* (*Entom. Monthly Mag.*, London, 1886, XXIII, pp. 97–99).

Except the silk-worm and the honey-bee, I hardly know of any insect that can show an historical record equal to that of *Eristalis tenax*. The record begins in the dusk of the pre-historic times, and continues up to the present date. In its earliest days *E. tenax* appears like a myth, a misunderstood and unnamed being, praised for qualities which it never possessed, a theme for mythology in prose and poetry; later on, the bubble of its glory having burst, it gradually settles into a kind of commensalism with man, it obtains from him "a local habitation and a name," it joins the Anglo-Saxon race in its immense colonial development, it vies with it in prodigies of fecundity, and at present renders hitherto unrecognized services in converting "atrocious stuff" into pure and clean living matter.

I close this chapter on the *Bugonia*-craze with the moral of it, contained in another sentence from Goethe:

"Man sieht nur was man weiss."*

HEIDELBERG, *June*, 1893.

* We see only what we know.

COMPARATIVE LOCOMOTION OF DIFFERENT ANIMALS.*

By E. J. Marey,
Member of Institute of France.

In the study of organized beings, it is a matter of special interest to seek for the tie which exists between the special structure of each species and its characteristic functions. The more and more intimate union of anatomy and comparative physiology will, without doubt, lead to the discovery of the fundamental laws of morphogeny, laws which will permit us from the form of an organ, to foresee its peculiar uses. These relations are already partially within our grasp, so far as the locomotor apparatus of vertebrates is concerned. The volume and length of muscles, the relative dimensions of the bony rays of the limbs, the form and extent of the articular surfaces, permit us to predict the gait of a mammal. And, on the other hand, the correctness of these predictions may be tested by means of chrono-photography, which fixes the character of these movements in a series of instantaneous images.

The readers of this journal already know how the gait of man, of the horse, and of the principal mammals may be represented by true geometrical diagrams on which one can readily trace the angular motions of the different segments of the limbs, and the speed of each part of the body, at every instant and for each gait.

The different types of flight among birds and insects have also been studied by means of chrono-photography. This method can be extended to the analysis of the locomotion of all living beings, even to those moving in the field of the microscope. This done, it will then be possible to unite and classify in a pictorial atlas a series of types of animal locomotion. These types, compared with the anatomical descriptions of the various species will furnish the necessary elements for the comparison which we wish to make.

It will be a work of time to gather and compare all these anatomical and physiological data. The principal difficulty in the way of studying

*Translated from *La Nature,* September 2, 1893; vol. XXI, pp. 215–218.

different types of locomotion is encountered not so much in obtaining great numbers of species of animals alive, but in finding suitable methods for photographing each of them in its normal gait.

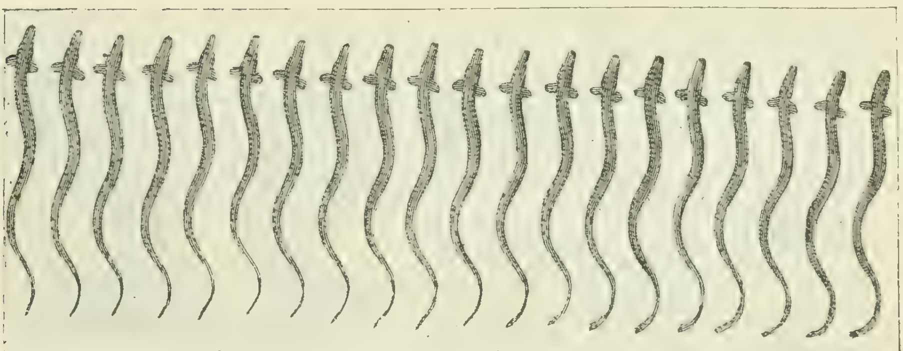
The greater part of domestic animals lend themselves very well to these studies: they are readily led to a track prepared and will travel over it regularly. With wild birds the difficulty is greater; we have however succeeded in obtaining a number of types.

Fishes, reptiles, mollusks, and insects are more difficult to manage; it is necessary to devise for each species some method which will compel it to travel regularly before the camera. Moreover, we must, according to circumstances, so vary the conditions of illumination that the animal will sometimes show dark on a light ground, and sometimes appear light upon a dark background. I have succeeded, nevertheless, in obtaining good pictures of a considerable number of different species, as may be judged from the illustrations (Pl. XXIII–XXV). This series of figures shows certain analogies in the mode of progress of species which approach each other in their anatomical characters. Thus the adder and the eel both progress by means of horizontal undulations which move over the entire length of the body from the head to the tail (Pl. XXIII). The analogy would be still greater if the eel and the serpent both swam in the water, or crawled upon the earth, for it is the resistance of the medium, or in other words the nature of the point of support, which governs the motions of crawling. In water the undulations of the body are more regular and more efficacious than on the ground, while at the same time they are less extended, and the retrograde speed of what we may call the wave of motion is but little less than the animal's rate of progress. That is, by the time an undulation has run from head to tail the animal has advanced by nearly the length of its body. On level ground, and still more on a slippery surface, the undulations of the serpent and eel are very much extended and progress is slow.

Among coleopterous and orthopterous insects progress is much as it has been described by naturalists. Carlet and M. de Moore have shown that insects rest on three legs while the other three move. The supporting legs constitute a triangular base, formed by the first and third leg of one side, and the middle leg of the opposite side. (Pl. XVIII, XXIV.)

Among arachnids there are on either side two supporting legs, and two legs raised at the same time. But in the spider and scorpion which we have taken as types, the walk is so rapid that it is not easy to follow the successive motions in their proper order although they were photographed at the rate of 60 a second. In such cases it is necessary to increase the number of figures, and above all, to resort to such methods of illumination as we have adopted in studying the spider. This consists in so illuminating the animal above and below, that while it is clearly shown in outline, its shadow is projected upon the track over

1. SNAKE CREEPING. (Succession of figures from left to right.)



2. EEL SWIMMING. (Succession of figures from right to left.)

3. COLEOPTERUS INSECT WALKING. (Succession of figures from left to right.)
(Reproduced from "La Nature.")

which it runs. This shadow gives much information in regard to the position of the legs for when the feet are resting on the ground the leg and its shadow touch at their extremities. (Pl. XXIV.)

One of the most interesting points in these physiological comparisons is to see how the anatomical resemblances of different animals correspond with their functional resemblances.

Among fishes, for example, we meet in varying degree, with the reptilian undulation which forms the eel's sole mode of progress, but find that it has lost much of its importance. Still very apparent in the dog-fish (Pl. XXV) it is found only in the caudal region of those fishes whose thick set bodies have lost the greater part of their flexibility, but in these cases the widened tail acts more efficiently for it meets with great resistance in the water.

Batrachians in different phases of their development have modes of locomotion corresponding to the state of their organs. The tadpole of a toad, in which the feet are still imperfectly developed (Pl. XXV, fig. 2, upper line) swims with its tail after the fashion of a fish. Later on (lower line) the legs begin to be used for locomotion, but the tail still keeps up its energetic action and vibrates continually, while the legs move in alternate jerks. Still later (middle line) the tail has disappeared and the hind legs are alone used in progression. This role of the hind limbs which presents so striking an analogy to the swimming of man is effected in the following manner.*

The animal flexes its legs, bringing them well under the body, then spreads them wide apart in such manner that the two legs, directed laterally, form a right angle with the axis of the body. Propulsion is effected by bringing the outstretched feet quickly together, after which they are gradually flexed and brought towards the body, and the series of movements recommences.

The lizards, which anatomically approach the serpents, also preserve in their progression something of the undulatory movement which we have represented above, but this undulation is complicated by the action of the limbs, which play the leading part in the crawling of these reptiles (Pl. XXV). In the gecko (Pl. XXV) the undulation of the body is plainly to be seen; it is scarcely apparent in the gray lizard. In both species it is impossible for the eye to follow the incessive movements of the feet, and to compare them with those of other quadrupeds, but from their chrono-photographic images it is easy to see that, taking the order of the movements of the limbs as a standard, the lizards are trotting animals. The limbs, in short, move diagonally—that is, the right fore leg and left hind leg, move simultaneously.

The undulations of the body are so combined with the movements of the legs that the feet are brought close together on the concave side

* Several of the views shown in the illustrations have been reversed.

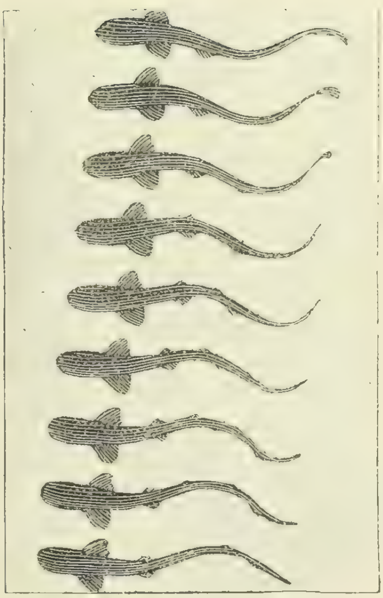
of the wave, and widely separated on its convex side. This implies an absolute agreement between the number of undulations of the body and the steps of the animal.

It is easy to see from the examples just cited that chrono-photography gives us vastly more information on the subject of animal locomotion than we can gain by the closest observation, and that, thanks to this method, we can, as previously said, compare the anatomical structure and the functional characters among the different species of animals.

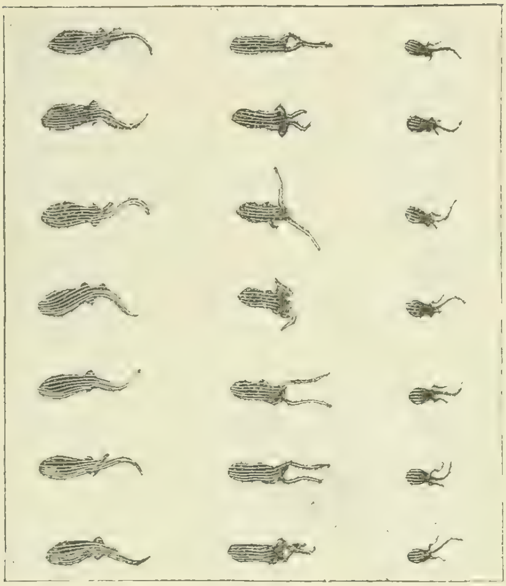
1. Orthoperus Insect Walking. (Succession of figures from right to left.)

2. Spider Walking. (Succession of figures from left to right.)

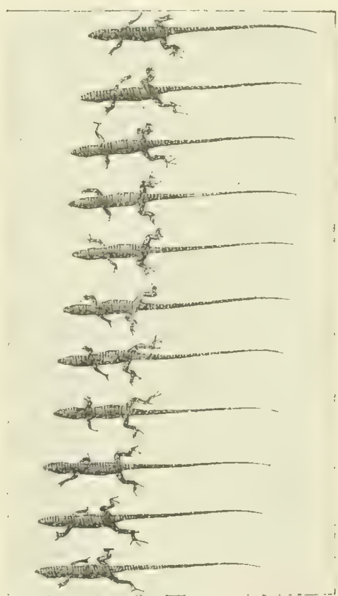
3. Locomotion of a Scorpion. (Succession of figures from left to right.)
(Reproduced from "La Nature.")



1. Dogfish Swimming. (Succession of figures from right to left.)



2. Swimming of a toad and a tadpole in different stages of development.



3. Gray Lizard. (Succession of figures from right to left.)

4. Gecko. (Succession of figures from left to right.)

THE MARINE BIOLOGICAL STATIONS OF EUROPE.*

By Bashford Dean,
Columbia College, New York.

Among European nations the marine laboratory has long been recognized as an important aid to the advancement of biological studies. Groups of universities, centralizing their marine work in convenient localities, have caused the entire coast line of Europe to become dotted with stations, well equipped and well maintained. Societies, individuals, and not infrequently governments contribute to their support.

Marine stations have become distributing centers, important equally in every grade of biological work or training. A student, for example, should he visit a small university in the interior of France, would receive his first lessons, aided by material sent regularly from Roscoff or Banyuls; he would examine *living* sponges, pennatulids, beroës, hydroids, Loxosoma, Comatula, Amphioxus. Or, at Munich, remote from the coast, as in the laboratory of Prof. Richard Hertwig, he is enabled by means of material from Naples to demonstrate the larval characters of ascidians or the fertilization processes of the sea-urchin. During his winter studies the marine station would thus provide him with the best material—sometimes preserved and well fixed, sometimes living, to be prepared according to his wants. In summer it affords him the best opportunities to see and collect his study types without physical discomforts and with the greatest economy of time. To the investigator the station has become, in the broadest sense, a university. He may there meet the representative students of far and wide, fellow-workers perhaps in the very line of his own research, and must himself unknowingly teach and learn. He finds out gradually of recent work, of technical methods which often happen most pertinent to his needs. He carries on his work quietly and thoroughly; his works of reference are at hand; he has the most necessary comforts in working, and is untroubled by the rigid hours of demonstrations or lectures. The station becoming a literal emporium, cosmopolitan, bringing together side by side the best workers of many universities, tends moreover to make

*In the main as published in the Biological Lectures, 1893, of the Woods Holl Marine Laboratory. (Boston: Ginn & Co.)

observations upon the best material sharper by criticism, most fruitful in results. It has often been remarked how large a proportion of recently published researches was dependent, directly or indirectly, upon marine laboratories.

A brief account of the more important of these stations should not prove lacking in suggestions; especially as in America the work of the marine laboratory is often imperfectly understood. Its aims have been associated popularly with those of practical fish culture; and even among the trustees of universities a disposition has often been to regard an annual subscription for a work place in a summer school as among the little-needed expenditures of a biological department. So little important has a marine station seemed that the greatest difficulties have ever been encountered to insure the support of an American table at Naples, although it was well known how large a number of our investigators were each year indebted to foreign courtesy for the privileges of this station.

General interest in the advancement of pure science has in Europe become a prominent feature of the past decade, and there can be no doubt of the importance that has come to be attached to studies bearing upon the problems of life, evolution, heredity. Nor, at the same time, does it appear that matters relating to practical fisheries have in any way lost their interest or support. To these, on the contrary, the rise of pure biology has often given important aids. What has appeared abstract theory to-day has often been converted into practice to-morrow. And even so ardent a partisan of pure biology as Prof. de Lacaze-Duthiers does not hesitate to urge this, as sufficiently important in general argument, to vindicate the governmental support of the laboratories of Roscoff and Banyuls. "Facts have been found at every step of science which were valueless at their discovery, but which, little by

little, fell into line and led to applications of the highest importance—how the observation of the tarnishing of silver or the twitching leg of the frog was the origin of photography or telegraphy—how the purely abstract problem of spontaneous generation gave rise to the antiseptics of surgery.

As a preface to the present discussion the general number and location of the European marine stations might conveniently be indicated in the accompanying outline map.

I.—FRANCE.

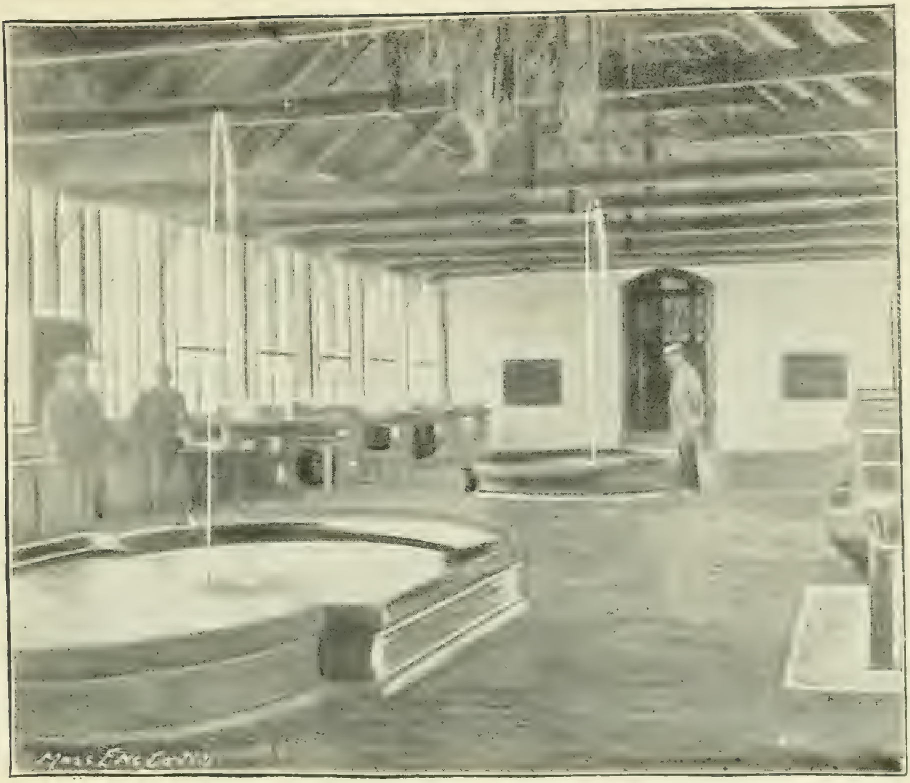
The extended sea-coast has ever been of the greatest aid to the French student. Along the entire northern coast the channel is not unlike our Bay of Fundy in the way it sweeps the waters out at the lunar tides. The rocks on the coast of Brittany, massive bowlders, swept and rounded by swift running waters, will at these times become exposed to a depth as great as 40 feet. This is the harvest time of the collector. He is enabled to secure the animals of the deep with his own hand, to take them carefully from the rocky crevices where they would ever have avoided the collecting dredge. From earliest times this region has not unreasonably been the field of the naturalist. It was here that Cuvier, during the Reign of Terror, made his studies on marine invertebrates which were to precede his *Règne Animal.* The extreme westernmost promontories of Brittany have, for the last half century, been the summer homes of de Quatrefages, Coste, Audouin, Milne-Edwards, and de Lacaze-Duthiers. Coste created a laboratory at Concarneau, but this has come to be devoted to practical fish culture, and is, at the present day, of little scientific interest. It is owing to the exertions of Prof. de Lacaze-Duthiers, of the Sorbonne, that the two governmental stations of biology have since been founded. The first was established at Roscoff, in one of the most attractive and favorable collecting regions in Brittany, and has continued to grow in importance for the last twenty years. As this station, however, could be serviceable during summer only, it gave rise to a smaller dependency of the Sorbonne in the southernmost part of France, on the Mediterranean, at Banyuls, which had the additional advantage of a Mediterranean fauna.

To these French stations should be added that of Prof. Giard, at Wimereux, near Boulogne, in the rich collecting funnel of the Straits of Dover; that of Prof. Sabatier, at Cette, not far from Banyuls, a dependency of the University of Montpelier; that of Marseilles, and the Russian station at Ville-Franche, near the Italian frontier. An interesting station, in addition, is that at Arcachon, near Bordeaux, founded by a local scientific society. Smaller stations are not wanting, as at the Sables d'Olonne.

At Roscoff the laboratory building looks directly out upon the channel. (Pl. XXVI.) In its main room, on the ground floor, work places are partitioned off for a dozen investigators; this on the one hand leads to

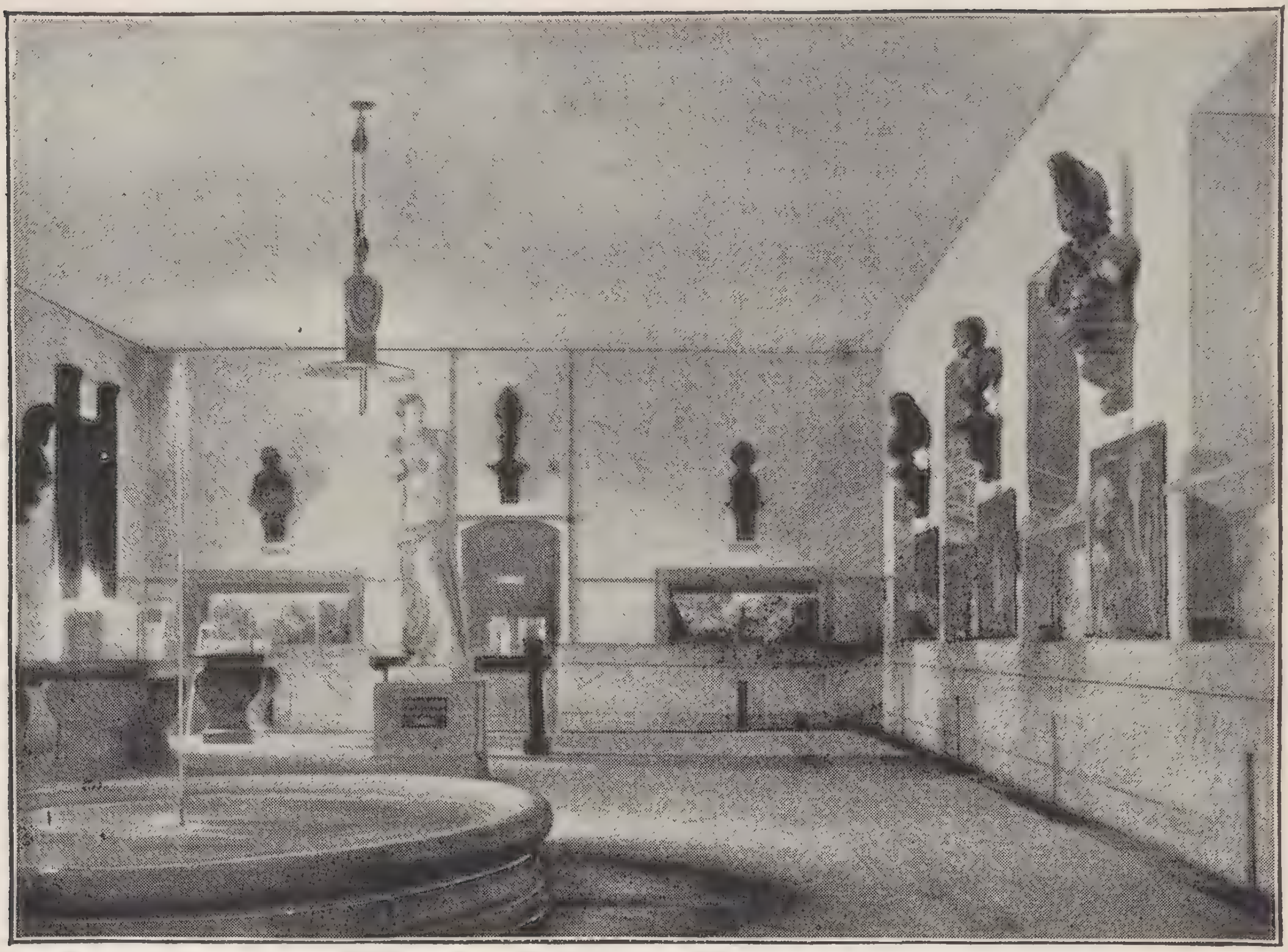
a large glass-walled aquarium room, seen in the accompanying figure, while on the other opens directly to adjoining buildings, which include lodging quarters, a well-furnished library, and a laboratory for elementary students. Surrounding the building is an attractive garden, which gives one anything but a just idea of the barrenness of the soil of Brittany. From the sea wall of the laboratory one looks out over the rocks that are becoming exposed by the receding tide. A strong inclosure of masonry serves as a *vivier* to be used for experiments as well as to retain water for supplying the laboratory. The students are, in the main, those of the Sorbonne, and under the direction of Dr. Prouho, their *maître de conferences.* They are given every opportunity to take part in the collecting excursions, frequently made in the laboratory's small sailing vessels, among the rocky islands of the neighboring coast. Strangers, too, are not infrequent, and are generously granted every privilege of the French student. Liberality is one of the characteristic features of Roscoff. The stranger who writes to Prof. de Lacaze-Duthiers is accorded a work place which entitles him gratuitously to every privilege of the laboratory—his microscope, his reagents, even his lodging-room should a place be vacant. It seems, in fact, to be a point of pride with Prof. Lacaze that the stranger shall be welcomed to Roscoff, and upon entering the laboratory for the first time, feel entirely at home. He finds his table in order, his microscope awaiting him, and the material for which he had written displayed in stately array in the glass jars and dishes of his work place. So, too, he may have been assigned one of the large aquaria in the glass aquarium room—massive stone-base stands, aërated by a constant jet of sea water. He finds a surprising wealth of material at Roscoff, and his wants are promptly supplied.

At Banyuls (Pl. XXVII), the second station of the Sorbonne, the buildings are less imposing than those of Roscoff. It is a plain, three-story building facing the north, at the edge of the promontory which shelters the harbor at Banyuls. The *vivier* is in front of the station, behind is a reservoir cut in the solid rock, receiving the waters of the Mediterranean and distributing it throughout the building. On the first floor is a large aquarium room lighted by electricity, well supplied with tanks and decorated not a little with statuary donated by the administration of the beaux-arts. The bust of Arago occupies an important place, as the laboratory has been named in his honor. A suit of a diver suggests the different tactics in collecting made necessary by the slightly-falling tides of the Mediterranean. The wealth of living forms in the aquaria shows at once by variety of bright colors the richness of southern fauna. Sea lilies are in profusion, and are gathered at the very steps of the laboratory. The work rooms of the students are on the second floor, equipped in a manner similar to those of Roscoff. The directer of this station is Dr. Frédéric Guitel. It is usual during the



ROSCOFF. INTERIOR OF AQUARIUM ROOM. (JULY, 1891.)

FRENCH MARINE STATION AT ROSCOFF.



BANYULS-SUR-MER. INTERIOR OF AQUARIUM ROOM. (OCTOBER, 1891.)

FRENCH MARINE STATION AT BANYULS-SUR-MER. (OCTOBER, 1891.)

holidays at fall or winter for the entire classes of the Sorbonne to spend several days in collecting trips in the neighborhood. The region with its little port is famous for its fisheries, and one in especial is that of the angler, *Lophius*, a fish that would not be regarded as especially dainty on our side of the Atlantic.

The station on the Straits of Dover, at Wimereux, has earned a European reputation in the work of Prof. Giard. It is but a small frame building, scarcely large enough to include the advanced students selected from the Sorbonne. The laboratory is, in a way, a rival of Roscoff, and it is noteworthy that its workers seem to make a point of studying the laboratory details of the German universities.

The marine laboratory of Arcachon, one of the oldest of France, was built in 1867 by the local scientific society, and was carried on independently until the time of the losses of the Franco-Prussian war. Its management was then fused with that of the faculty of medicine of Bordeaux, with whose assistance, aided by that of a small subsidy from the Government, the work of the institution wascarried on. Arcachon, near Bordeaux, is in itself a most interesting locality. It has become a summering place, noted for its pine lands and the broad, sandy *plage*, picturesque in summer with swarms of quaintly dressed children, the local headdress of the peasant mingling with the latest toilet from Paris. Here and there is to be seen that accompaniment of every French watering place, the goat boy in his smock and berret, fluting to his dozen charges, who walk in a stately way before him. The Bay of Arcachon is a small, tranquil, inland sea, long known for its rich fauna. In large part it is laid out in oyster parks, which constitute to no small degree the source of wealth of the entire region. Shallow and warm waters seem to give the marine life the best conditions for growth and development. The laboratory is placed just at the margin of the water. It includes a dozen or more work-places for investigators, well supplied with aquaria, a library on the second floor, a small museum containing collections of local fauna, including numerous relics of Cetaceans that have found their way into this inland sea. A small aquarium room, opened to the public, is well provided with local forms of fishes, and like that of Naples, is eagerly visited. Those who are entitled freely to the use of the work-places are instructors in French colleges, members of the society, and all the advanced students from the colleges of the State. For other students work-place is given upon the payment of a fee whose amount is regulated each year by the trustees. As at Roscoff, material is plentifully supplied.

The zoological station at Cette is a direct annex of the University of Montpelier, and it will be gladly learned that its temporary building is being replaced by one of stone, which will enable Prof. Sabatier to add in no little way to the working facilities of his students. The region, in every essential regard, is similar to that of Banyuls.

The station at Marseilles is devoted in a great part to questions relat-

ing to the Mediterranean fisheries, and owes, in a measure, its financial support to this practical work.

Villa Franca (Ville-Franche), between Nice and Mentone, is one of the most interesting points of the Riviera. Its laboratory is situated directly on the mole, a large one-storied building of masonry, with a small garden, and with several shops and out-houses. It is supported essentially by Russians, and its description has recently been published by Prof. Alexis Korotneff (Russian text, Cracow), one of whose figures is here reproduced. The station has had as a constant visitor Prof. Carl Vogt, of Geneva, and is well known through the work of Dr. Bolles Lee.

II.—ENGLAND.

The laboratory at Plymouth is quite a recent one, its foundation due in the first instance to the efforts of Prof. Ray Lankester. Its building, first opened in 1888, is, in many regards, hardly second to Naples. This locality was found well suited for the needs of an extensive marine station. Opposite Brittany it takes advantage of the same extremes of tide, and the rocky Devonshire coast affords one of the richest collecting grounds. The situation of the building is a remarkable one; it stands at one end of the ancient Hoe of Plymouth—a broad, level park whose high situation looks far off over the channel. At the rear of the building are the old fortifications of the town. As shown in the illustration (Pl. XXIX, fig. 2), the building is, at the ends, three-storied. On the ground floor is the general aquarium room, well supplied with local marine fauna, and open to the public. The laboratory proper is upon the second floor, divided into eleven compartments, the work places of the students. A series of small tanks passes down the middle of the room. In the western end are the library, the museum, the chemical, photographic, and physiological rooms; in the eastern are the living quarters of the director. The water supply of the laboratory is contained in two small reservoirs directly between the building and the fortifications, and is carried throughout the building by gas engines. Tidal aquaria are in constant use for developmental studies. The collecting for the laboratory is aided by a 38-foot steam launch.

The present support of the station is not, unfortunately, as generous a one as might be desired. The station is obliged to consider in the work of its director matters relating to public fisheries, and is only enabled by this means to secure governmental assistance. The build- itself was constructed by the efforts of the Marine Biological Association of the United Kingdom, under whose auspices the present work is being carried on. The investigators' tables are occupied by any founder of the association, or his representative, by the naturalist, or institutions who have rented them. The subscription price per year of an investigator's place is £40, but tables may be leased for as short a time as a month. The laboratory provides material for investigation and the

ordinary apparatus of the marine laboratory, excluding microscopes and accessories. The use of the larger tanks of the main aquarium is also permitted to the working student. The work of the laboratory includes investigation of fishery matters, the preservation of animals to supply the classes of zoology in the universities and the formation of type collections of the British marine fauna. The naturalist of this station has been for a number of years Mr. J. T. Cunningham, whose experiments upon the hatching of the sole have here been carried on.

Other British marine stations are those of Puffin Island, Liverpool, and St. Andrews, northeast, and Dunbar, southeast, of Edinburgh. The work of these stations, it is understood, is only in part purely biological. The practical matters of fisheries must be considered to insure financial support. In addition to these is to be mentioned a station, recently equipped, on the Isle of Man. Still another has recently (the latter months of 1893) been established at Jersey, in the Channel Islands.

Zoological station at St. Hélier, Isle of Jersey.

The foundation of this station has been entirely due to private enterprise, and its management seems both independent and practical. The proprietors, Messrs. Sinel and Hornell, add to the station's revenue by providing alcoholic material for class work, anatomical preparations, serial sections. They also edit and publish an interesting little quarterly, Journal of Marine Zoology and Microscopy.

The station will doubtless prove a welcome need to the traveling biologist who finds, at a half day's journey from England, a richer fauna than even Plymouth can offer. It is readily open to investigators upon payment of a small weekly fee. Of the building and its equipment, a brief description might here be given. It is situated east of St. Helier, at a ten-minute's walk from the town, facing the main road, La Collette, overlooking a picturesque and rugged shore. It is but 18 feet above tidal mark, and at low water, especially at lunar tides, is immediately adjacent to a rich collecting ground. Twelve square miles of "zostera prairie" are there exposed, and may be visited

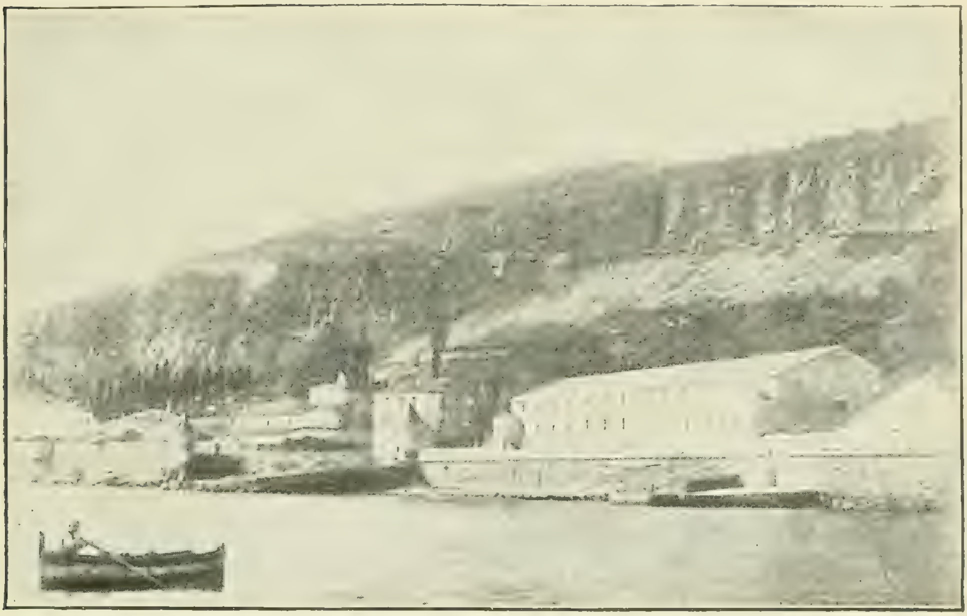
afoot. And the Minquier reefs, of especial biological interest, are but 9 miles to the southward.

The station is a stone building of three stories. The aquarium, on the ground floor, is mainly for purposes of exhibition, its adjoining room serves to receive and assort the collected material. The second story contains the museum and library, serving at the same time as a demonstration hall, and upon the third floor are the partitioned compartments for the use of students and investigators.

At St. Andrews, Prof. Macintosh has studied the questions relating to the hatching and development of the North Sea fishes. Its situation upon the promontory leading into the Firth of Forth seems to have been especially favorable for the study of the North Sea fauna, notably of larval and embryonic stages of fishes, and the locality, moreover, from its northern position represents a number of boreal forms. The importance of St. Andrews is at length better recognized, and a substantial grant from the Government will enable a large and permanent marine station to be here constructed. The facilities for work have, up to the present time, been somewhat primitive—a simple wooden building, single-storied, has been partitioned off into small rooms, a general laboratory, with work places for half a dozen investigators, a director's room, aquarium, and a small out-lying engine house with storage tanks. To the laboratory belongs a small sailboat to assist in the work of collecting.

III.—HOLLAND.

Holland, in the summer of 1890, opened its zoological station in the Helder, a locality which, for this purpose, had long been looked upon with the greatest favor. (Pl. XXX, fig. 2.) There is here an old town at the mouth of the Zuyder Zee, the naval stronghold of Holland, a station favorable for biological work on account of the rapid-running current renewing the waters of the Zee. The station was founded by the support of the Zoological Society of the Netherlands, whose valuable work by the contributions of Hubrecht, Hoek, and Horst, has long been known in connection with the development of the oyster industry of Holland. The work of the society had formerly been carried on by means of a portable zoological station which the investigators caused to be transplanted to different points along the East Schelde, favorable on account of their nearness to the supplies of spawning oysters. The present station at the Helder is situated directly adjoining the great dike, a small stone building, two story, surrounded by a small park, as seen in the adjacent figure. In itself the laboratory is a model one. The rooms are carefully finished, and every arrangement has been made to secure working conveniences. A large vestibule leads directly into two laboratory rooms and, by a hallway, communicates with the large, well-lighted library and the rooms of the director. The aquarium room has,



RUSSIAN STATION AT VILLE-FRANCHE, FRANCE, NEAR THE ITALIAN FRONTIER.

ROSCOFF, BRITANY. VIEW OF COURT YARD OF BIOLOGICAL STATION.

for convenience, been placed in a small adjacent building. The director of this station is Prof. Hoek, and the president of the society is Prof. Hubrecht.

IV.—NAPLES.

The Stazione Zoologica at Naples during the past twenty years has earned its reputation as the center of marine biological work, publishing in its *Mittheilungen* the results of its researches, and in its *Jahrsberichte* a summary of the year's contributions to biological sciences. It has afforded a locality most favorable for marine research, and has offered every convenience for continued studies; it has been the supply center for living and preserved material for the majority of the European universities; it has published the results of its investigations in its monographs and bulletin in a way that has left little to be desired; the range of its researches has been of the widest and most varied interest, botanical, zoological, developmental, physiological, morphological. Indeed it may strictly be said that within an equal period of time it has contributed more to the advancement of pure biology than has any other institution in the world.

The success of the Naples station has doubtless been aided by the richness of the fauna of the gulf, but is mainly and unquestionably due to its energetic and careful administration. The director of the station, Prof. Dohrn, deserves no little gratitude from every worker in science for his untiring efforts in securing its foundation and systematic management. Partly by his private generosity and partly by the financial support he obtained, the original or eastern building was constructed. Its annual maintenance was next assured by the aid he obtained throughout (mainly) Germany and Austria. By the leasing of work tables to be used by the representatives of universities a sufficient income was maintained to carry on the work of the station most efficiently. A gift by the German Government of a small steam launch added not a little to the collecting facilities.

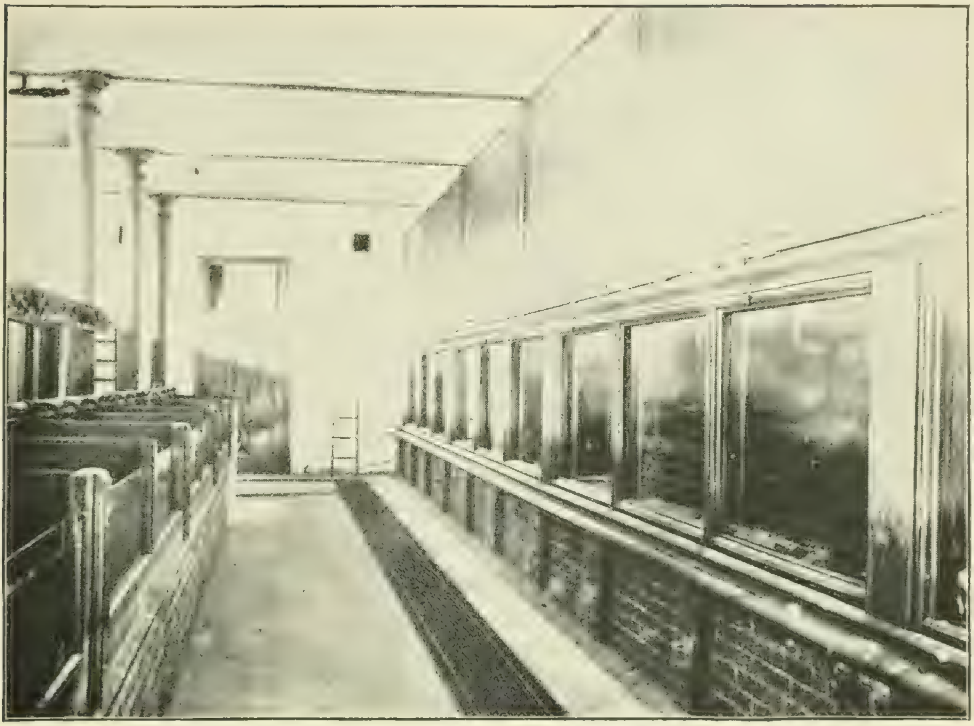
Attractiveness is one of the striking features of the Naples station. It has nothing of the dusty, uncomfortable, gloomy air of the average university laboratory. Its situation is one of the brightest; it has the gulf directly in front, about it the city gardens rich in palm trees and holm oaks. The building itself rises out of beds of century plant and cactus like a white palace; the fashionable driveway alone separates it from the water's edge. In full view is the island of Capri, to the eastward is Vesuvius—a bright and restful picture to one who leaves his work for a five minutes' stroll on the long covered balcony which looks out over the sea.

The student, in fact, knows the Naples station before he visits it, although he can hardly anticipate the busy and profitable stay that there awaits him. He has received the circular from the secretary of

the laboratory while perhaps in Germany, when he secured the privilege of a table. He is told of the best method of reaching Naples, the precautions he must take to secure the safe arrival of his boxes and instruments. He is told to send directions as to the material he desires for study; he is notified of the supplies which will be allowed him, and of the matters of hotels, lodging, and banking, necessary even to a biologist. At the first sight of the building he is impressed most favorably, and it is not long before he comes to look upon his work-place as his particular home, open to him day, night, and holiday. He likes the general air of quietness—in no little way significant of system in every branch of the station's organization; his neighbors are friendly, and he feels that even the attendants are willing, often anxious to give him help.

At present the station at Naples consists of two buildings, the first, shown in the foreground in the accompanying illustration (Pl. XXXI), is the older, the main building; behind it is the newly built physiological laboratory. In the basement of the main building is the aquarium, well managed, open to the public, and eagerly visited. Passing into the aquarium room from the main entrance, one descends into a long, dark, concreted room, lighted only through wall tanks brilliant on every side with varied forms of life. There are in all about two dozen large aquaria embedded in the walls of the sides and of the main partition of the room. The water is clear and blue. The background in each aquaria, built of rock work, catches the light from above and throws in clear relief the living inmates. The first tank will perhaps be full of starfish and sea urchins, bright in color, often clustered on the glass each with a dim halo of pale, thread-like feet. In the background may be a living clump of crinoids, flowering out like a garden of bright-colored lilies.

In a neighboring tank, rich with dark-colored seaweeds, will be a group of flying gurnards, reddish and brilliantly spotted, feeling cautiously along the bottom with the finger-like rays of their wing-shaped fins. Here, too, may be squids, delicate and fish-like, swimming timidly up and down; perhaps a series of huge triton snails below amid clustered eggs of cuttlefish. In another tank would be a bank of sea anemones with all the large and brilliant forms common to southern waters. Here may be corals in the background and a forest of sea fans in orange, red, and yellow, with a precious fringe of pink coral, flowering out in yellow star-like polyps. There may again be a host of ascidians, delicate, transparent, solitary forms, the lanky Ciona, the brilliantly crimson Cynthia, and huge masses of varied, compound forms. Swimming in the water may be chains of Salpa and occasionally a number of Amphioxus; the latter, as they from time to time emerge from the sandy bottom, flurry about as if with sudden fright, quickly to disappear. Variety is one of the striking characters of neighboring tanks. In one, brilliant forms will outvie the colors of their neighbors; in another, the



PLYMOUTH. INTERIOR OF AQUARIUM ROOM.

BRITISH MARINE LABORATORY, PLYMOUTH. (AUGUST, 1892.)

least obtrusive mimicry will be exemplified. The stranger has often to examine carefully before, in the seemingly empty tank, he can determine on every side the living forms whose color characters screen them effectively. Thus he will see sand-colored rays and flounders, the upturned eyes of the curious star-gazer almost buried in the sand, a series of mottled crustaceans wedged in a rocky background, an occasional crab wandering cautiously about, carrying a protective garden of seaweeds on his broad back; odd sea horses posing motionless mimicking the rough stems of the seaweeds. In the larger tank sea turtles float sluggishly about; and coiled amid broken earthern jars are the sharp-jawed murrys, suggestive of Roman dinners and of the cultural experiments of Pollio. Aëration in the aquaria is secured effectively by streams of air which are forced in at the water surface and subdivide into bright clouds of minute silvery bubbles. The tanks are cared for from the rear passageways; attendants are never seen by visitors, and constant attention has given the aquaria a well-earned reputation. Well-illustrated catalogues in French, German, English, and Italian enable the stranger to be better appreciate the aquarium.

To the remainder of the building strangers are not admitted. A marble stairway leads from the door of the aquarium to a loggia which opens into the territory of the students. A long pathway of grating extends across the open center of the building—whose skylight top admits the light to the aquarium below. On the one hand is the main laboratory room, on the other the library and separate rooms intended for more fortunate investigators. One enters the main laboratory, passes a wall of student aquaria, and sees a series of alcoves formed by low partitions, each work-place with its occupant, his apparatus, his books, his jars—altogether often a picture not of the utmost tidiness. A small iron staircase leads to a gallery, which gives a second tier of work-places and doubles the working capacity of the room. Here, side by side, will be representative workers from universities of every country of Europe.

The library room adds not a little to the attractiveness of the Naples station. (Pl. XXXI, fig. 1.) It is a long room, and, as shown in the figure, is adorned with frescoes in a truly Italian style. It looks out into a long *loggia* with view of the sea and Capri, where the student is wont to retire in after luncheon hour with easy chair and book. The working library is of the best, and is sure to contain the results of the most recent researches. The desk shown in the figure is one on which each day is to be found the latest publications. In the upper pigeon holes are the cards prepared for each investigator on his advent to Naples; with these he replaces the volumes which he has taken to his work place. Every division of the laboratory is carefully organized, and is under the charge of a special assistant. Prof. Hugo Eisig, the assistant director, has taken the welfare of each student under his personal

charge, and it is not until the end of his stay that the visitor recognizes how much has been done for him.

There is no more interesting department of the station than that of receiving and distributing the material. Its headquarters is in the basement of the physiological laboratory, and here Cav. Lo Bianco is to be found busy with his aids and attendants amid a confusion of pans, dishes, and tables, encountering the Neapolitan fishermen who have learned to bring all of their rarities to the station. The specimens are quickly assorted by the attendants; such as may not be needed for the immediate use of the investigators are retained and prepared for shipment to the universities throughout Europe. The methods of killing and preserving marine forms have been made a most careful study by Lo Bianco, and his preparations have gained him a world-wide reputation. Delicate jelly-fish are to be preserved distended, and the frail forms of almost every group have been successfully fixed. The methods of the Naples station were kept secret only until it was possible to verify and improve them, as it was not deemed desirable to have them given out in a scattered way by a number of investigators.

Lo Bianco has made the best use of the rich material passing daily through his department, and has been enabled to prepare the most valuable records as to spawning seasons and as to larval conditions. He knows the exact station of the rarest species, and it seems to the stranger a difficult matter to ask for a form which can not be directly or indirectly procured. It adds no little to the time saving of the student to find each morning at his work place the fresh material which he has ordered the day before, often in embarrassment rather than dearth of riches.

A collecting trip often occurs as a pleasant change from the indoor work of the investigator. An excursion to Capri may be planned; the launch will be brought to the quay near the station, and the party will embark. The collecting tubs are soon scattered over the deck, and filled with the dredge contents. Some of the passengers are quickly at work sorting out their material, one seizing brachiopods, another compound ascidians, another sponges. Others will wait until the surface nets have been brought in and the contents turned into jars. All will depend upon Lo Bianco as an appellate judge in matters of identification.

Many Americans have availed themselves of the privileges of Naples, and the former lack of support of an American table needs little comment. Of those who have hitherto visited Naples more than three-quarters have been indebted to the courtesies of German universities. At present, of the two American tables one is supported by the Smithsonian Institution, the other by gift of Mr. Agassiz.

The entire Italian coast is so rich in its fauna that it is due perhaps only to the greatness of Naples that so few stations have been founded. Messina has its interesting laboratory well known in the work of its

director, Prof. Kleinenberg. The Adriatic, especially favorable for collecting, has at Istria a small station on the Dalmatian coast, and at Trieste is the Austrian station.

V.—TRIESTE.

Trieste possesses one of the oldest and most honored of marine observatories, although its station is but small in comparison with that of Naples, Plymouth, or Roscoff. Its work has in no small way been limited by scanty income; it has offered the investigator fewer advantages and has therefore become outrivalled. During the greater part of the year it is but little more than the supply station of the University of Vienna, providing fresh material for the students of Prof. Claus. Its percentage of foreign investigators appears small; its visitors are usually from Vienna and of its university.

Trieste is, in itself, a small but busy city, growing in active commerce. Its quays are massive and bristle with odd-shaped shipping of the eastern Mediterranean. Its deep and basin-like harbor affords a collecting ground as rich as the Gulf of Naples.

The station has been located at a quiet corner of the harbor, just beyond the edge of the light-house. (Pl. XXXII, fig. 2.) Its building is somewhat châlet-like, situated on a small, well-wooded knoll, as seen in the adjacent figure. About it are trellis-covered grounds inclosed by high walls, and separated from the harbor only by the main roadway of the quays. One enters the laboratory garden through a large gateway and passes into a courtyard whose outhouses disclose the pails and nets of the marine laboratory. Perhaps an attendant will here be sorting out the rarities which a bronze-legged fisherman has just brought in.

A library and the rooms of the director, Dr. Graeffe, are close by the entrance of the building. In the basement is the aquarium room—somewhat dark and cellar-like; its tanks small and shallow, their inmates representing especially stages of Adriatic hydroids and anthozoans. On the second story are the investigator's rooms—large, well lighted, looking out over garden and sea. Near by is a museum of local fauna, rich in crustaceans and in the larval stages of Adriatic fishes.

VI–IX.—GERMANY, NORWAY, SWEDEN, RUSSIA.

The German universities have contributed to such a degree to the building up of the station at Naples that they have hitherto been little able to avail themselves of the more convenient but less favorable region of German coasts. The collecting resources of the North Sea and of the Baltic have perhaps been not sufficiently rich to warrant the establishment of a central station. On the side of the Baltic, the University of Kiel, directly on the coast, may itself be regarded as a marine station. At present the interest in founding local marine laboratories has, however, become stronger. The newly acquired Heligoland has become

the seat of a well-equipped governmental station. (Plate XXXIII.) The island has been long known as most favorable in collecting regions, and its position in the midst of the North Sea fisheries gives it especial importance. Its present building is three-storied, of stone, situated near the water in the small town on the Jutland side of the island. As yet the station has not to compete with its larger rivals, but its work has been so designed on the sides of pure biology, botany, and practical fisheries, that its growth seems an assured and speedy one. Work-places are provided for four investigators. Its director is Dr. F. Heinke; his assistants, Drs. Hartlaub, Ehrenbaum, and Kuckuck.

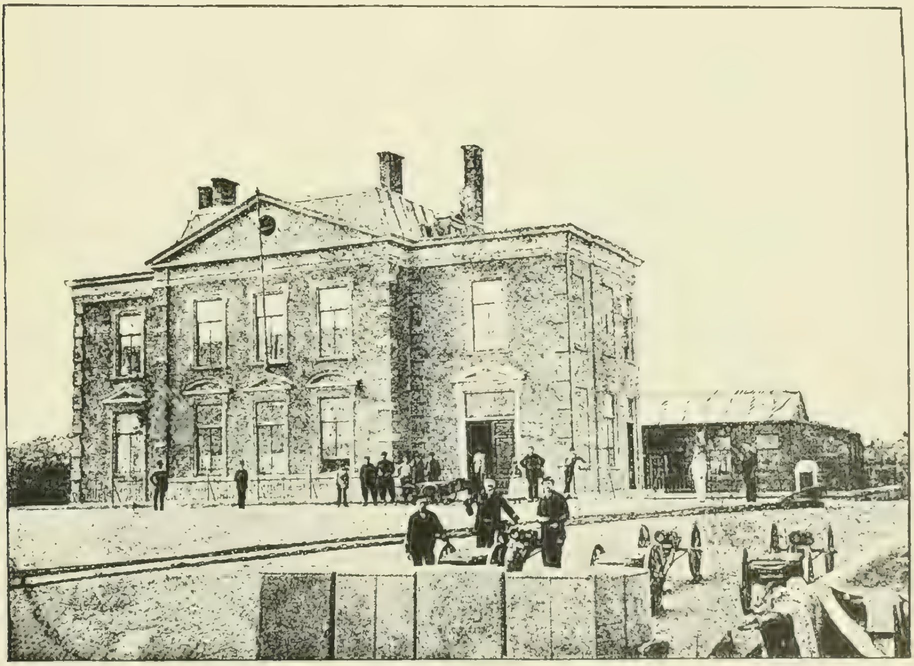
The Istrian laboratory at Rovingo, a favorable collecting point on the Adriatic, is to be included among the German stations. It was destined by Dr. Hermes, its founder, as the supply depot of the Berlin aquarium. Of its work-places, two have been rented by the Prussian Government, and a third is at the disposal of Dr. Hermes.

Germany, however, is *facile princeps* in its active aid in the promotion of fresh water stations; that situated on the margin of the lake of Plön, in Holstein, near the Baltic, deserves, even in this connection, a passing notice. Its building and equipment are certainly as complete as of the best class of marine laboratories (Pl. XXXIV); its management is an entirely similar one, and its director, Dr. Otto Zacharias, has given it every care to make its success permanent and increasing. The publication of its Forschungsberichte has already given it a prominent place among the stations of biological research.

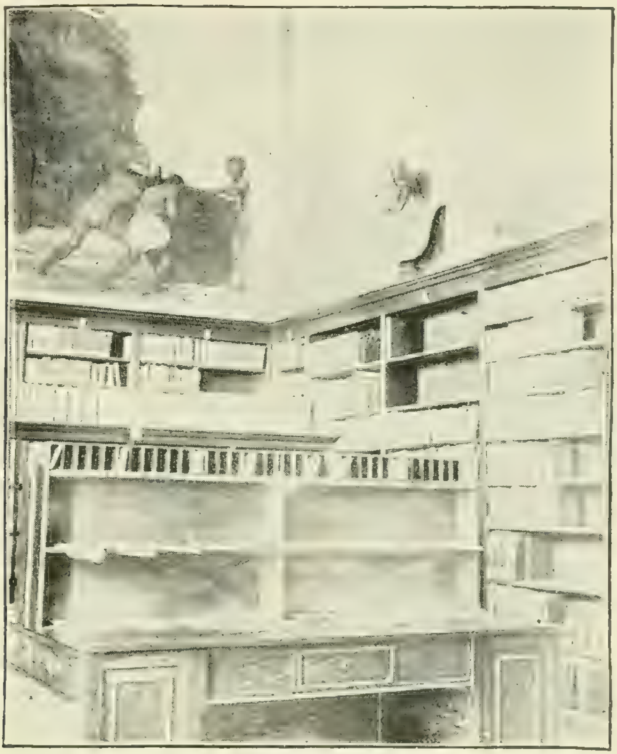
Norway, like Germany, is strengthening its interest in local marine laboratories. Two permanent stations have quite recently been established, one at Bergen, the other at Dröbak, a dozen miles south of Christiana. The former is the larger, a dependency of the museum of Bergen. It is under the charge of Dr. Brunchorst, to whom its foundation is due, and Drs. Appellöf and Hansen. Its two-storied villa-like building provides work places for eight investigators. A well-maintained aquarium on the first floor is open to the public. The second and smaller station is devoted almost exclusively to research in morphology. It is a dependency of the University of Christiana and is under the directorship of one of its professors, Dr. Johan Hjort. With the richest collecting resources these new stations may naturally be expected to yield most important results.

The Swedish station has long been associated with the work of its late director, Prof. Loven. It is situated on the west coast near the city of Gothenburg. Its three original buildings, a laboratory and two dwelling houses, were constructed about fifteen years ago by a gift of Dr. Regnell, of Stockholm. The laboratory is a wooden building well furnished with aquaria, provided in its second story with separate work-places for investigators. It is at present maintained by governmental subsidy. Its recently appointed director is Dr. Hjalmar Theel, of the State Museum at Stockholm. Its students are mainly from the Uni-

ZOOLOGICAL STATION AT ST. ANDREWS, SCOTLAND.

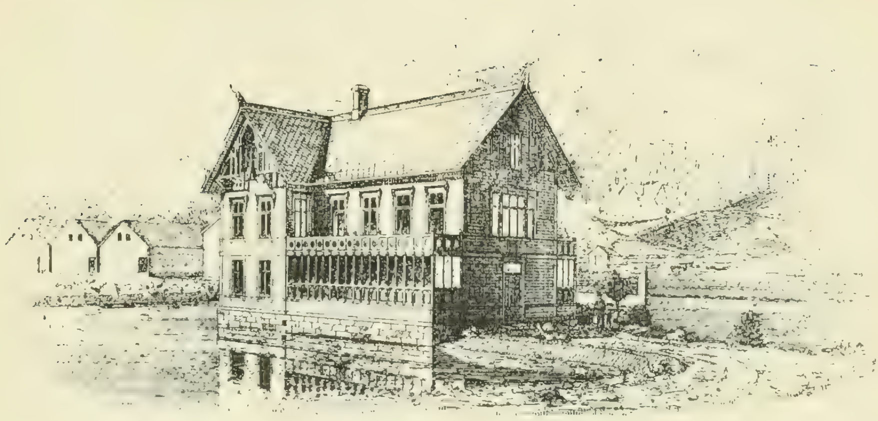


DUTCH ZOOLOGICAL STATION AT THE HELDER.
Figure from Tijdschr. d. Ned. Dierk. Vereen, 5 Juli, 1890.



THE LIBRARY OF THE NAPLES STATION. (JUNE, 1892.)

THE ZOOLOGICAL STATION AT NAPLES. (MAY, 1892.)



BIOLOGICAL STATION AT BERGEN, NORWAY.

THE STATION AT TRIESTE.

THE STATION AT HELIGOLAND.

BIOLOGICAL STATION ON LAKE OF PLÖN (HOLSTEIN) NEAR KIEL.

versity of Upsala. Up to the present time foreigners have not been admitted.

Russians have ever been most enthusiastic in marine research, and their investigators are to be found in nearly every marine station of Europe. The French laboratory on the Mediterranean at Ville-Franche is essentially supported by Russians. At Naples they are often next in numbers to the Germans and Austrians. The learned societies of Moscow and St. Petersburg have contributed in no little way to marine research. The station at Sebastopol, on the Black Sea, has become permanent, possessing an assured income. That near the Convent Solovetsky, on the White Sea, though small, is of marked importance. It is already in its thirteenth year. Prof. Wagner, of St. Petersburg, has been its most earnest promoter as well as constant visitor. He, in fact, caused the superior of the convent to become interested in its work and secured a permanent building by the convent's grant; he was then enabled by an appropriation from the Government to provide an equipment and is now agitating the matter of the appointment of a permanent director. The annual maintenance of the station is due to the Society of Naturalists of St. Petersburg. Solovetskaia is said to possess the richest collecting region of the Russian coasts. Its labratory is certainly the only one which has at its command a truly Arctic fauna.

THE AIR AND LIFE.*

By Henry de Varigny.

Every living thing breathes, and to maintain life air is as essential as water and food and a certain degree of heat. This sounds like an altogether commonplace idea, and one over which there would be no reason to linger were it not that modern science in its exact analysis of phenomena has brought to light many curious facts which show how varied are the relations between the living organism and its environment.

Before we discuss these various relations, let us say a few words about the air itself. It surrounds our globe on all sides to a height not actually known, but as life probably can not be maintained beyond 10,000 or 15,000 meters, the air beyond that distance is of no interest for our present purpose. It appears, also, that there is no life in our seas at a depth greater than 8,000 or 10,000 meters, so that we may say that all living things are contained in a stratum not more than 20,000 or 25,000 kilometers thick. In this thin layer, wherein life attains its maximum density at its central part, represented by the sea level, all living organisms are contained. It is small when compared with the dimensions of the earth and the immensities of celestial space, but it becomes all the more wonderful in view of the variety of the forms evolved in it and the development attained by some of them.

Each organism bears its portion of the weight of this atmosphere, a person of average stature supporting several thousand kilograms. The air contains aqueous vapor, holds in suspension different sorts of dust, is stirred by numberless motions; and each of these qualities has an effect upon life.

Chemically considered, air is composed of various elements. It is not a simple body, as was supposed up to the end of the last century, but a mixture of gaseous bodies, susceptible of analysis and separation. It is a mixture and not a combination, for its elements unite without electric or thermic phenomena, and it is a mixture in which the relative proportions of the component parts may be considered as practically constant.

Three of its elements preponderate either as to quantity or in physi-

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ological importance, viz, oxygen, nitrogen, and carbonic acid. Where do these elements come from? What is their proportion? What becomes of them? We naturally ask these questions, and it does not seem out of place to consider them here. In our examination of the relations between the atmosphere and the living being our chief concern will be the influence of organisms on the air, although in the course of our study the influence of air upon organisms will also come under notice.

I.—CONSTITUENTS OF THE ATMOSPHERE.

Oxygen was discovered by Priestley and Scheele in 1774. Not long after, Lavoisier proved by very simple experiments that oxygen is one of the constituent elements of air and that air itself is a compound—a mixture of gases. The reader could not do better than to consult on this point Mr. Berthelot's interesting book, *La Revolution Chimique.* The term oxygen was invented by Lavoisier. Its discovery made a revolution in chemistry and in physiology and was the beginning of an era which has been fertile in wonderful results.

Oxygen is a gas heavier than air and is specially favorable to combustion and respiration. In 1,000 liters of air there are 208 liters of oxygen and 792 liters of nitrogen. These figures have been obtained by the numerous and very exact methods now used in chemistry, and the same methods have been employed to determine the constancy of the proportion of oxygen. Such investigations were necessary, because certain chemists, Dalton and Babinet among others, thought that from theoretical considerations the proportion of oxygen in the air ought to decrease as the elevation increases, that at the surface of the earth there ought to be a little less oxygen and a little more nitrogen, while in the upper regions of the atmosphere the relative proportions would be reversed, so that at an altitude of 10 kilometers, for example, the volume of oxygen would be 184 to 816 of nitrogen. Direct analysis, however, made by Thenard of air obtained by Gay-Lussac at an altitude of 7,000 meters, and the experiments of Dumas and Boussingault made by means of the weighing method, have proved that the facts do not confirm those theories. The relative proportions of oxygen and nitrogen in the air, then, may be said to be uniform and constant, except for slight occasional variations.

Dumas and Boussingault, who studied the air for oxygen in different kinds of weather at different altitudes, in different places and at different seasons, obtained practically identical results, with the usual allowance for errors. Other chemists, Brunner, Regnault, Reiset, Doyère, and Bunsen, have all by different methods reached the same conclusion, which may, therefore, be considered as firmly established.

Our first question is where does this oxygen in the air come from? What are its sources? The permanence of the proportion of the gas in the air and the enormous quantity of it consumed by living beings and in combustion naturally lead us to desire an answer on this point.

What we know about it is that more than a trillion kilograms are contained in the air; that it constitutes nearly half the weight of the minerals of the globe and eight-ninths of the weight of water, and that it abounds in the tissues of all living things. At present, however, but one source of oxygen is known, viz, plants, a discovery made by Priestley and explained by Perceval and Senebier. Vegetables have the property, due to their chlorophyll, of decomposing carbonic acid into its elements, carbon, which becomes fixed in their tissues, and oxygen, which, on being freed, diffuses itself through the atmosphere. There are, of course, many chemical reactions which effect a liberation of oxygen, such as the electrolysis of water, the decomposition of chlorate of potassium, or sulphuric acid by heat, but is it from such reactions as these or from others which occur naturally, that this gas is liberated into the atmosphere? We do not know. But the fact being accepted that the composition of the air remains constant, there must be some processes by which the enormous volume of oxygen, absorbed as it is by organic and inorganic combustions at every second in every portion of the globe, is restored sooner or later to the atmosphere. Is it possible for plants to perform all this chemical labor? This is a question we ask without being as yet able to answer. Everything seems to indicate however that they do suffice for it.

Although the proportion of oxygen in the air is constant, or practically so, yet it must not be forgotten that certain local conditions tend to increase or diminish its usual ratio. The air loses oxygen in places crowded with living beings, in places where substances oxidize either slowly or rapidly, as in public halls, for instance, or in mines, and a chemical analysis of air quickly shows its condition. Wherever there is consumption of oxygen without sufficient circulation of air the proportion of oxygen is lessened. These local variations, however, do not affect the composition of the whole any more than it is affected by forests, where there is abundant production of oxygen.

Let us now proceed to consider nitrogen. This gas was discovered by Rutherford in 1772, and was proved by Lavoisier to enter into the mixture which we know under the name of air. It is lighter than air and forms seventy-nine one-hundredths of its bulk. It neither burns nor is it combustible. It does not serve for respiration, nor can it sustain life. It is not toxic, but merely inert, indifferent, and for respiratory purposes inactive. Our knowledge of its origin is limited. We know that it is produced by certain thermal springs, the sulphurous ones in particular. We know that it is contained in the excretions of animals and that they have absorbed it from the air they have breathed. Like oxygen, it seems to be present in air everywhere in the same proportions.

These two elements, oxygen and nitrogen, form the largest and the most essential parts of the air. The elements which we shall now consider are only small and variable portions, we might almost say acces-

sories were it not that analysis shows their part in life to be almost as important as the fundamental and essential elements.

The chief of the accessory elements is carbonic acid. Very small quantities of it exist in the air in proportions of 4 or 5 to 10,000 volumes of air. Relatively it is a heavy gas and distinctly unfavorable to respiration or combustion, as Priestley discovered. Its proportion in the air is not fixed, but varies according to place and condition much more than does that of the other gases. De Saussure discovered very marked variations as long ago as 1827, varying between 3·15 and 15·74 per 10,000. Boussingault and Lévy found a difference between Paris and Andilly of 3·19 in the town and 2·99 in the village. Roscoe and McDougall found not so much difference between Manchester and its environs, but at Clermont-Ferrand M. Truchot gives figures of 3·15 per 10,000; at Puy de Dome, of 2·03, and at Pic de Sancey, 1·72. These examples are enough to show that the quantity of carbonic acid in the air varies considerably and that the air of high places and of the country is much purer than in towns. A variation also is produced by the seasons, the month, and the year, and De Saussure notes an increase of the gas at night and in cloudy weather. But these variations occur in an irregular manner from day to day, although they seem less marked above the sea, the air being purer there, as on high mountains. Again, these variations are much greater in places where the air does not circulate freely and where organic or inorganic combustions are taking place. This is not a matter of surprise when we remember that the air we have this moment exhaled contains 100 times more carbonic acid than the same air when we inhaled it some seconds ago. This being the case, we have only to take a close room with one or more persons in it, and in time we could note all the possible proportions of carbonic acid were it not that the experiment is self limited. The normal proportion of carbonic acid, as stated by Pettenkoffer, is 0·04 or 0·05 per 1,000. This may increase in an ill-aired room to 0·54 or 0·70, and in an ill-ventilated sick room to 2·4. In a lecture room it may go up to 3·2, in a schoolroom to 7·2, and even to 21 in an Alpine stable, where men and beasts huddle together in winter, stopping the chinks against the cold. But there soon comes a limit; the men or the animals die sooner or later and the production of carbonic acid ceases. They die, killed by excess of carbonic acid and by lack of oxygen. A place containing more than 4 per cent of carbonic acid and less than 16 per cent of oxygen, which are the proportions in expired air, becomes rapidly fatal to life. But we shall take up this point again when we come to speak of the relations of carbonic acid to life. Our object here is to point out that the proportion of carbonic acid increases largely in a confined locality and that its proportions vary more than those of oxygen and nitrogen.

The variations depend upon the rate of production of the gas in question, and on that point we know relatively a good deal. Carbonic acid has many sources, one of which we have mentioned in passing.

All living beings are producers of carbonic acid, and all breathe, although with varied force. Respiration, chemically considered, is the combination of a certain quantity of carbon of the body and a certain quantity of oxygen of the air; it is a manufacture of carbonic acid which is expelled by the lungs. This constant evolution of carbonic acid by animals and also by plants, which breathe like animals, certainly varies in intensity; and we know that in the same species of animal, for example, the male produces more than the female, the adult more than the very young or the very old, the strong more than the weak, etc. Everyone knows also that this production is increased by exercise, by movement, by sunlight, by the taking of food: diminished by rest, by darkness, by want of food. It may be said that on the average man exhales 20 liters of carbonic acid every hour, or nearly a kilogram in the twenty-four. The sheep produces more and the bull about 7 and 8 kilograms. To fully appreciate, however, the rate of production of carbonic acid by animals, let us state it differently and bring it down to a common unit, the kilogram of the weight of an animal. The total amount produced will then be compared with the number of kilograms that the animal weighs, and we can say that a kilogram of horse or ox, or of duck, produces such and such a quantity every twenty-four hours. By this method we find that birds are the greatest producers of carbonic acid. A kilogram of ox excretes from 3 to 7 grams of carbon every twenty-four hours, a kilogram of turkey about 20 grams, a kilogram of newly-hatched chicks 56 grams, and of sparrows nearly 60 grams. This ought not to surprise us, for we know that the respiratory activity of birds is very great, and the consequent production of carbonic acid necessarily large.

Boussingault made the calculation, some time ago, that the city of Paris alone produces from men and horses about a half a million cubic meters every twenty-four hours. At the present time these figures would be much larger, and if we estimate the total population of the globe at a thousand million, the conclusion is evident that man alone casts off 480,000,000 of cubic meters of carbonic acid per day into the atmosphere; in other words, 175,200,000,000 of cubic meters per year! It is difficult to calculate the exact production for animals, but it is certainly double or triple, according to Girardin. We may call the amount produced by animals and men together 700,000,000,000 of cubic meters per year. If we add to this the productions from plants, from the combustion of wood and coal, the slow production from the whole terrestrial surface where vegetable matter is decaying, from mineral sources, from volcanoes and their surroundings (Cotopaxi exhales, according to Boussingault, more than all Paris), from natural springs, from terrestrial depths, it will not surprise us that Mr. Armand Gautier concludes that 2,500,000,000,000 [2½ billion] of cubic meters of carbonic acid is produced every year. And even that enormous sum is certainly less than the actual fact.

With this formidable amount of production in view, we may well be astonished that the proportion of carbonic acid in the atmosphere remains so slight, for we can easily calculate what proportions it would reach in ten, twenty, or a hundred years, and how fatal such proportions would be to life, were there not some cause constantly at work destroying this gas. We are sure therefore that some powerful means eliminates this gas from the atmosphere in about the proportion in which it is produced. Three of these means we know, viz, animals, plants, and the sea.

Although plants by their respiratory function are exhalers of carbonic acid, they absorb a much larger quantity of it for their nutrition. They absorb this gas and decompose it into its elements, carbon, which becomes part of their tissues, and oxygen, which they restore to the air. Plants are great producers of oxygen.

Next in order of carbonic-acid destroyers are animals having skeletons or calcareous carapaces, such as shellfish, corals, nearly all marine and terrestrial animals which form carbonate of lime. Van Dechen has estimated that the calcareous strata of the carboniferous rocks alone contain six times more carbon than the atmosphere now has, a fact which suggested to Sterry Hunt, the American geologist, that there must be some other source of carbonic acid, namely, interstellar space. Indeed, if the carboniferous rocks should liberate into the atmosphere all the carbonic acid they contain, the pressure upon that gas would be so great that a large part of it would be soon liquified or even solidified. (Stanislas Meunier.)

Lastly, the sea has a most important part in the absorption and regulation of the production of carbonic acid, and thus prevents its accumulation in the air beyond certain limits. Experiments made by Mr. Schloesing prove that sea-water holds in solution a much larger quantity of carbonic acid than the air contains. When carbonic acid increases in the air on account of a production in excess of the destruction, a portion of it becomes dissolved in the sea water and unites with the neutral insoluble carbonate of lime that that water always contains to form a soluble bicarbonate. Inversely, when the quantity of carbonic acid diminishes in the atmosphere, the soluble bicarbonate decomposes into the neutral carbonate which remains in the sea, and into carbonic acid, which penetrates into the atmosphere. In short, when there is equilibrium of tension between the carbonic acid of the atmosphere and the acid of the sea water, nothing is produced, but the moment the equilibrium of tension is destroyed the sea proceeds, by this simple chemical process, to restore it. This adjustment, constantly going on, is made possible because the sea contains a much greater amount of carbonic acid than the atmosphere—ten times more according to a calculation of Mr. Schloesing. However great, then, the production of carbonic acid may be on the surface of the globe by all the agents we have enumerated, we are certain that

the proportions of this gas in the atmosphere as a whole can vary but slightly, owing to the power of the sea to absorb the gas and maintain the equilibrium.

There is no doubt that oxygen, nitrogen, and carbonic acid are the most important elements of the air from a chemical standpoint. Other bodies, however, are normal in the atmosphere. Ammonia is one of them. It has been found by G. Ville in the extremely small proportion of 24 grams per 1,000,000 kilograms of air. Nitric acid is another which has been discovered in rain water in the proportion of 1 to 10 milligrams in a liter of water. Ozone also is found, oxygen that has become condensed or in some way more potent under the influence of atmospheric electricity. But as a matter of fact these bodies exist in the air in very trifling proportions and there is no need to consider them further at present. Their functions with regard to life are, however, clear, and we will mention them again further on.

II.—CHEMICAL EFFECTS OF ATMOSPHERIC GASES.

Having now become acquainted with the elements of the atmosphere, their relative proportions in the aërial mixture, the manner in which they are produced and destroyed, and assuming that it is a fairly well established principle that the composition of air varies but little, remaining the same within the above indicated limits, and having shown the part performed by animate life in maintaining the composition of the atmosphere, we may now discuss the functions of the atmosphere with reference to animate life.

For simplification we shall make a separate examination of the function performed by the several constituent elements of air. Oxygen is, to all appearances, the vital gas par excellence, and with it we shall begin. It is universally known to be necessary for the respiration of animals and men, and its great usefulness has been clearly demonstrated by physiology. Man is a great consumer of it, inhaled air containing on an average from 20 to 21 volumes of oxygen while there are but 16 volumes in exhaled air, the organism therefore has absorbed 4 volumes. In twenty-four hours the human body retains over 740 grams, or 516,500 cubic centimeters, representing for all mankind an aggregate of 500,000,000 cubic meters per day. Children and aged people consume less oxygen than the middle aged, the latter absorbing 914 grams in twenty-four hours, while 375 grams suffice for a child of 8 years. Various other conditions also exert a perceptible influence, a person's vigor, sex, external temperature, inaction or activity either increasing or diminishing the consumption of oxygen. The gas is absorbed by the tissues which it reaches chiefly through the lungs and blood, although one eightieth as much as is taken up by the lungs is absorbed by the skin. All living tissues require oxygen, for all breathe, and the lungs are nothing but the instrument of respiration. The chemical operation by which respiration is essentially constituted is performed elsewhere, in the

tissues themselves. The lungs, notwithstanding the opinion of physiologists of the last century and of Lavoisier himself, are but the inlet through which the vital gas is admitted. Respiration is an operation essentially chemical; the oxygen in air passes through the walls of the exceedingly fine capillaries of the lungs, where it finds in the red globules of blood a certain substance, hemoglobin, which unites with it by virtue of its chemical affinity and transports it to every part of the organism, there to assist in the chemical operations, especially the oxidations which attend life in the cells and tissues or in the organs formed by them. The result is a production of carbonic acid, the oxygen of which is supplied by the air and the carbon by the tissues. Blood is then nothing but a vehicle; it brings the requisite oxygen to the tissues and carries off the carbonic acid which would soon cause death, if allowed to accumulate there.

While respiration is common to all animals, it is far from being equally active in all; it is more intense in birds than in mammals, in mammals than in reptiles and mollusks; on the other hand, an active animal will consume more oxygen than a slothful one or one plunged in sleep, lethargy or hibernation. Yet all animals breathe; none can dispense with oxygen, and if that gas fails them, they die.

It is not otherwise with vegetables. True, plants exhale oxygen through their function of nutrition, but, as was pointed out by Priestley, they absorb some through their function of respiration. With them also this function may vary in intensity. During germination a large quantity of oxygen is required and we thus understand why so many seeds can not germinate under water where the supply of oxygen is insufficient, or in compact soils that are not easily penetrated by air. One seed may demand one-hundredth of its weight in oxygen, another seed will thrive on one-thousandth or one-half of one-thousandth, but all need some. Plants also require oxygen during growth; they consume it in large quantities when blooming, at which time chemical operations are so rapid and so intense as to give rise to quite a perceptible production of heat. At every instant in their lives they consume oxygen, and it is for this reason that large quantities are not kept in our dwellings, especially at night, when they produce carbonic acid, oxygen being exhaled only by day. Even when apparently dead, plants still breathe; their separated parts—blossoms, leaves, fruits—inclosed in a vase filled with air, consume oxygen and produce carbonic acid. If placed in a medium devoid of oxygen, death speedily follows.

So then, no life is possible without oxygen, neither for animals nor for plants. This much has been determined by science since the day of Lavoisier's discovery.

The hasty conclusion might be reached by some that an unusual proportion of oxygen makes life more intense, and that wherever there is a lack of air life is also absent. Investigations by Paul Bert, and especially by M. Pasteur, during the last fifteen or twenty years, have shown how erroneous are such conclusions.

Living beings are adapted for life in an atmosphere containing one-fourth oxygen and three-fourths nitrogen. Experiments show that if the proportion of oxygen be decreased even by one fourth the air can not sustain life. The adaptation of living beings to the atmosphere is thus confined within narrow bounds, and it is therefore proper to ask whether a variation in the opposite direction, that is, by excess of oxygen, would not likewise be injurious to life. Paul Bert contributed much toward a solution of this problem. Experiments have established a fact that seems very strange at first, but which will less surprise those accustomed to consider the adaptation of living beings to their environment. Oxygen, the vital and pre-eminently vivifying gas, is also a virulent poison, not only for animals, but for plants; for cells as well as for the entire organism. If the tension of the oxygen of the air be raised to a certain degree, or, what amounts to the same thing, if its volume be increased to a certain proportion, that air becomes at once a death-dealing agent. This can be demonstrated in two ways, either by subjecting the animal or plant to an abnormal atmospheric pressure or by placing it in air in which the proportion of oxygen has been artificially increased. In both instances the same phenomena take place and death soon supervenes. The cause for this is not well known as regards plants, but Paul Bert has shown that animals die in an atmosphere overcharged with oxygen as soon as their blood contains one-third more than the normal proportion of oxygen. The reason for this is that the hemoglobin in the blood, coming in contact with such atmosphere, becomes saturated with oxygen, and after that a portion of that gas at once dissolves in the blood, or rather in its liquid serum. Therein lies the cause of all the mischief, that oxygen carried in the serum is dissolved, free, uncombined, and on coming in contact with the tissues it kills them. Here we have the method of the process, but the cause is not yet understood. We can only state the fact that tissues can not stand free oxygen and will take and utilize that gas only by borrowing it from the red globules which convey it in their hemoglobin as already explained. In other words living tissues absorb oxygen indirectly and will not tolerate it when directly supplied.

Notwithstanding all this, oxygen is none the less a powerful therapeutic agent. Like all poisons, it may be administered in beneficial doses and a salutary latitude exists between the normal quantity found in blood and that at which danger would begin.

This poisonous property of excessive oxygen is one of the most curious facts that recent years have brought to our notice, and it is so clear, so marked, that it can be no longer open to doubt.

On the other hand, a general statement that without oxygen there can be no life would be quite incorrect. Pasteur's investigations have shown that while certain microbes can live only with air and oxygen, there are others, which he has called "anaerobic," that thrive best when deprived of air. It is so with the micro-organisms which cause

fermentation. They produce fermentation only when in a medium devoid of oxygen, and M. Pasteur was fully justified in saying that fermentation is a consequence of life without air. What, then, occurs in a fermenting medium? A particular kind of microbe (each kind of fermentation being caused by a special microbe) transported by air or water, or intentionally introduced, has been living in that medium for some time on the oxygen therein contained. After a time, the free oxygen having been consumed by the microbe, the supply is practically exhausted. Some oxygen, however, is left in the medium, not free, but in combination with elements of the latter; and the microbe has the power of extracting or decombining that gas and of applying it to its own use. As this can only be done by destroying an existing chemical combination, the elements are released and, in the process of disengagement, cause the characteristic phenomena of fermentation. Thus, in the alcoholic fermentation of saccharine substances, as cane or grape sugar, the microbe removes from the sugar a portion of its component oxygen, thus decomposing it into free carbonic acid and alcohol. This is one illustration out of a hundred useless to enumerate. All experiments prove that wherever fermentation takes place a microbe is present, which, unable to find its requisite supply of oxygen, takes it from the surrounding substances by decomposing them and changing them into new compounds containing in part the same elements as the original, but differently united. Thus those microbes that are apparently most averse to the contact of air, the anaerobies, breathe oxygen like all other beings. We may practically conclude that life is not impossible in the absence of free oxygen, and at the same time we may assert that wherever there is life there is some means by which the living being can procure its supply of oxygen. The apparent exception in the case of the anaerobic microbes is therefore no exception.

Between the essentially anaerobic microbes and those that are aerobic, that require free oxygen, there are of course all the stages of transition and it would not be possible here to enter into all the particulars by which to show that differences exist only in degree. A reminder that vegetable cells, by reason of their aptitude to cause alcoholic fermentation, for instance, are both aerobic and anaerobic will suffice. "Let us put a beet in carbonic acid," says Mr. Duclaux, "we shall see it make alcohol. Let us also put cherries, plums, apples, any kind of sweet fruit, whole sacchariferous plants, again their sugar is partly turned into alcohol and carbonic acid. Under these novel conditions of life they in nowise differ from yeast, except that they are less able to endure life without air, that they do not carry fermentation so far, and that life ceases before a complete transformation of their sugar is accomplished. But these are mere differences in degree." We shall be less surprised at these differences if we recall the discoveries of Paul Bert, mentioned above, for we found that even animal tissues are anaerobic. Did we not see that tissues are killed by free oxygen dissolved in the serum of blood, and that they derive no advantage from

that gas unless they take it from the combination of oxygen with hemoglobin? Anaerobism is then a characteristic of animal tissues no less than of certain microbes, and yet none of them can dispense with oxygen. There is no life without oxygen; yet, no life with too much oxygen. Such is the conclusion that has been established by actual facts.

We shall now discuss nitrogen. As may be inferred from its other name, "azote," nitrogen is unfit for the sustenance of life, and any animal or plant placed in an atmosphere of nitrogen will die a speedy death. Not that this gas is poisonous, for we inhale it in large quantities without feeling its influence, but it is inert, ineffective, neither an agent in—nor a subject for—combustion. It has no share in respiration, and it would seem that its only function in the atmosphere is to mitigate the action of oxygen. Death would soon follow in an atmosphere of oxygen alone, through injury to the lungs and poisoning of the tissues, but when mixed with an inert gas the oxygen penetrates the oganism in moderate quantities only. Oxygen is tempered by nitrogen in the same manner as the alcohol in wine is tempered by water. That is, to be sure, a very useful function, but of a negative order. And yet what else can be expected of an inert gas? If however some account be taken of the chemical constitution of living beings and of the abundance of nitrogen they contain; if also account be taken of the fact that four-fifths of the atmosphere consists of nitrogen and that animals will die when deprived of nitrogenous food, as was shown by Magendie, it would seem that that gas must perform some other more important and active function. Let us take this well-established fact for a starting point: Nitrogenous food is indispensable to maintain life in beings of the higher orders. How can plants which directly or indirectly provide the nutriment of those beings, lay up a supply of nitrogen? The natural answer is, they take it from the atmosphere. But how?

That question is one that has engrossed the earnest attention of chemists and agriculturists, and in France, notably, Boussingault, Berthelot, Dehérain, and George Ville have devoted considerable time to its study. They ascertained that certain plants obtain nitrogen either in the form of nitrates produced by combination of the nitric acid of the air with substances in the soil, or in the form of ammoniacal vapors But M. Berthelot several years ago showed that there was another factor in the problem, that the soil doubtless contains microbes endowed with the power of so treating the nitrogen of air that it can be assimilated by plants. This theory has been fully confirmed by two German scientists, Messrs. Hellriegel and Wilfarth, whose most valuable investigations have been recently published. They discovered that certain plants, and especially leguminous ones, possess the property of thriving in soil poor in nitrates, and of taking the requisite quantity of nitrogen from the air by means of special microbes that live on their roots. If the microbes are destroyed, the growth of the plant will be stunted, if

they are aided in reaching the roots by means of sprinkling with water in which rich earth has been kept for a few hours, the plant will at once prosper. Better still, if two leguminous plants are put in sterilized soil, and if, as was done by M. Bréal of the Museum, a small quantity of the liquid, charged with microbes that fills the nodes of any thriving leguminous plant, be injected into the root of one of the two plants, it flourishes at once, whilst the other that was not inoculated remains stunted. There is no controverting this demonstration. The microbes on the roots of leguminous plants are agents through which plants assimilate nitrogen. A new study is open to agriculturists and there is no doubt that other facts of the same purport will be discovered in this unsuspected field of investigation. In our present discussion we need only know that atmospheric nitrogen is retained by plants, and, as we know that nitrogenous food is necessary to higher beings, and that the supply of such food can invariably be traced back to plants, we may conclude that the nitrogen of air is an indispensable agent in animal as well as vegetable life. Though an inert, and at first glance useless gas, it nevertheless performs an essential function in nutrition of all beings. Our legitimate conclusion therefore is that without nitrogen there can be no food, no plants, no life. It is proper to add that plants derive nitrogen not exclusively from air, for nitrates and ammonia also supply some, but these compounds are themselves drawn from atmospheric nitrogen and our proposition remains true.

We now come to carbonic acid. That gas, as we know, is in the highest degree a noxious element, and without doubt we shall find nothing but mischief to charge to its account. It is indeed noxious, and we lose no time in expelling it from our organism; it is irrespirable, and plants as well as animals soon die when placed in a medium containing even a comparatively slight proportion of it. Even 1 per cent of carbonic acid in air causes perceptible disorders to life, and when there is 10 per cent life is in danger, and death is but a question of time. The tissues are injured by blood charged with carbonic acid, and when we breathe an atmosphere rich with this gas the blood globules only imperfectly discharge the carbonic acid that they gathered from the tissues, and on returning to these tissues the blood is therefore charged with that gas and lacks oxygen, or, in other words, is quite unfit to support life. The reason why these blood globules retain the carbonic acid when coming in contact with impure atmosphere is that they are unable to throw it off unless its tension in the atmosphere be less than in the globules. Now, when that gas is superabundant in the atmosphere, its tension is greater there than in the globules, and, in the absence of any cause inciting separation from the globules, the gas is retained and suffocates the animal by killing its tissues. Before producing death there is a decided anaesthesia which Bichat fully proved by experiments, in which he injected into the carotid and nervous centers of an animal, venous blood charged with carbonic

acid and taken from another animal of the same species. It also produces insensibility when locally applied to the skin, a form of anaesthesia that has been long known and frequently utilized. Indeed, Pliny tells us, in his *Natural History*, that marble and vinegar benumb the parts to which they are applied, so that these may be cut or cauterized without causing pain. In this case the anaesthetizing agent is the carbonic acid set free by the action of the acetic acid of the vinegar on the carbonate of lime.

When carbonic acid acts upon the entire organism, instead of on a portion of it, as when inhaled into the lungs, it brings about a general anaesthesia which has been investigated by several scientists. One of these, M. Ozanam, was so well pleased with the result that he did not hesitate to recommend that carbonic acid be used for an anaesthetic instead of ether or chloroform. So far as we know his advice has not been followed and it is unlikely that surgeons will ever avail themselves of so dangerous an agent. Yet a number of cases are known where men were thoroughly infected with carbonic acid without suffering death. In all such cases, there has been complete anaesthesia, before which, as reported by some of the patients, they passed through a most enchanting stage, when they fancied themselves in the midst of enrapturing music and refulgent light. But this stage is soon followed by absolute loss of consciousness, and if the poisonous agent continues to pervade the blood or fails to separate from it, everlasting sleep is the result. Accidental deaths caused by carbonic acid are not rare, and have been noted wherever alcoholic fermentation runs its course as in breweries and wine vaults, and where there is a natural or artificial emission of carbonic acid gas as in caves or in close or poorly ventilated rooms crowded with men or animals. The air in public halls becomes rapidly vitiated. As much as 10 parts of carbonic acid per thousand have been found in theaters, in school-rooms, and in lecture-halls, and in a crowded stable on the Alps the proportion was as great as 21 parts of carbonic acid in 1 000 parts of air. Atmospheres of this description are poisonous, as has been proved. Thus, during the war in India, 146 prisoners were confined in a small room at 8 o'clock in the evening. At 2 in the morning only 50 were living, and at daybreak there remained only 23, and these were in a dying condition. In like manner, out of 300 prisoners locked in a poorly ventilated cellar after the battle of Austerlitz 260 were suffocated by carbonic acid after a few hours. A similar accident happened at the celebrated assizes of Oxford, when the judges and a portion of the audience were suffocated through the same agency. It may be that in those cases the influence of another poison, which in the opinion of M. Brown Sequard, is exhaled from the lungs, was superadded to that of the carbonic acid; but it must be conceded that the existence of such a poison is by no means certain although it seems probable. To return to cases of suffocation by carbonic acid, we may mention those in which men and animals are killed by gas that, after flowing from natural springs, accumulates in neighbor-

ing hollows. These "valleys of death" have been described by several explorers. No vegetation, no shrubs, not a blade of grass grows there, the sterility is absolute. The ground is bare, stony, and as if under the stroke of death. Here and there are scattered the bleaching bones of birds, mammals, or even of men, who unaware of the deadly properties of those accursed places, have attempted to cross them and have been overcome by the carbonic acid which, heavier than air, has accumulated in places sheltered from the winds.

Deadly alike for animals and plants, by which it is thrown off as soon as it has been formed in their tissues, the carbonic acid presents indeed the appearance of a death-dealing agent, the most noxious of all gases. The best that can be said is that it may act a kindly part in the hour of death of superior beings. It accumulates in the organism by slow degrees on the approach of death, which is almost invariably by asphyxia, and it may be that when man is falling into his last sleep, when his body is about to undergo the final dissolution, this gas serves to lull his intelligence, gently produce insensibility, and assist him through the final act of physical life. In any event, this is a likely supposition, and it would thus appear that this gas, which is said by some physiologists to usher us into this world by promoting child-birth, intervenes again to facilitate our exit.

This is not however the sum total of the action of carbonic acid in life. It has another function, more active, more essential, of deep interest, and which we ought not to overlook.

All animals, whether directly or indirectly, feed on plants, and plants take from the soil the greatest part of their mineral elements. Nitrogen and oxygen they take from the atmosphere, but whence do they draw the carbon that is so abundant in their tissues? Two sources of supply are known. Carbonic acid exists in the ground in the shape of carbonates formed by its combination with various substances, and in humus or surface soil composed chiefly of fragments of vegetation dead and decomposed. But inasmuch as humus was not available for the first plants, its carbon can not be taken into account. The carbonates in the ground seem therefore in accordance with the opinion of Mathieu de Dombasle and a number of agriculturists and chemists who followed him, to be the only purveyors of carbon necessary to plants. Still the experiments of Sprengel, of Saussure and of others, have shown that carbonates were credited with more importance than they really possess, and at a more recent date it has been proved by Liebig that plants thrive well in a soil destitute of carbonates. But whence then do they drive their carbon? We now know that they take it from the atmosphere. They possess the property of decomposing the carbonic acid of the air and of setting its elements free, releasing the oxygen and retaining the carbon in their tissues. The 41,000,000 hectares of cultivated land in France absorb at least sixty millions of tons of carbon each year. There are however two conditions without

which this important operation can not be accomplished: the plant must be supplied with chlorophyll, the green matter which imparts color to the leaves: there must also be solar light, and the temperature must not be too low. As a matter of fact, chlorophyll can only decompose carbonic acid in the light and under certain conditions of temperature: it ceases to operate in cold weather or in darkness, and when it is deficient, when there is a lack of leaves, the plant droops and dies from starvation. For it is a point worthy of our careful notice that the function of chlorophyll is one of nutrition, decidedly distinct from that of respiration, by the operation of which plants, after the manner of animals, absorb oxygen and throw off carbonic acid. These two functions are not equally active, the former being much more so than the latter, although it only operates by day. If it were not so and if the two functions were exactly balanced, it would be impossible for the plant to grow, as it would lose through the one what it gained through the other.

It is then chiefly by the medium of the leaves, and in a less degree by the roots, that the carbonic acid of the atmosphere is absorbed, and in any event, that gas must pass through the leaves, the green parts fed with chlorophyll, in order to be utilized by the plant.

We now see that this virulent poison, so decidedly noxious that it destroys animal life as soon as it accumulates even to a slight degree in the atmosphere, is one of the essential foundations of life on the globe. If it should disappear from air, vegetation would immediately die, and a few days would suffice to accomplish the death of all that breathes and moves on the surface of our planet. True, carbonic acid by itself is a most noxious substance to life; but when in normal proportions in the atmosphere it is as necessary and indispensable to life as it is fatal when the air is surcharged with it.

The foregoing are the relations of air, studied from the standpoint of its chemical composition, to life as it manifests itself on earth—of the normal air studied without regard to any artificial cause by which it may be vitiated—of physiological air, so to speak.

III.—MECHANICAL EFFECTS OF THE ATMOSPHERE.

We shall now discuss another phase of this complex question and turn our attention to air in connection with its weight. This aspect is quite as worthy of investigation as the foregoing, for there is a very positive relationship between life and atmospheric pressure.

As already said, the atmosphere has weight and air exerts a pressure on the earth and on all living beings. The pressure varies according to the level, being lighter in elevated regions and greater in low regions. As the barometer is carried from mountain tops toward the plains, then to the level of the sea and finally into the depths of mines, it plainly shows the increase in pressure. Slight variations of pressure have little effect on living beings; but when the difference is great,

when man rises in a balloon or climbs mountains, or betakes himself to places where the pressure is naturally or artificially great, he experiences certain effects which deserve some mention. Animals as well as men are sensitive to barometric variations, as may be easily verified by observation and experiment. It is not always essential to carry animals up in the air, or to take them down in diving bells that we may observe the manner in which they are affected by an increase or decrease of pressure, for the experimenter will also experience the same effects, the nature of which is such as to make the experiment superfluous; investigation may be conducted in the laboratory where, by means of special apparatus, it is possible to lessen the pressure of air to any desired degree, or again to enhance it to points which startle imagination, to such points that the air is liquefied, even solidified. With proper apparatus we can at will obtain a virtually absolute vacuum, or pressures of from 800 to 1,000 atmospheres; and thus have no difficulty in ascertaining the influence of atmospheric pressure on animate life, and in confirming the conclusions drawn from the valuable researches made in this field by Jourdanet, Paul Bert, and others.

A circumstance that should be noted from the very outset is that all beings, whether on land or in water, can stand without evil consequences certain variations in atmospheric pressure. Man, for instance, may work underground at a depth of 1 kilometer without suffering inconvenience from the increased pressure, and may rise to altitudes of 5 or 6 kilometers in the air without fatal results from decreased pressure. The same is true for birds and most mammals, and on the other hand fish that live in great depths can rise to a certain level without endangering life by lessened pressure, without bursting as they do when they rise too near the surface. But it is none the less certain that in variations of pressure there are limits beyond which no living beings can safely go, and that outside of such limits, which vary somewhat according to species or groups, all beings die when the pressure is increased or decreased. What is the process of death in both cases? That is the question that confronts us. Let us first consider the case of decreased pressure: what are the symptoms exhibited? Four hundred years ago the Jesuit missionary, Acosta, gave us an excellent account of the effects attending the ascent of high mountains, and consequently the effect of rarefaction of air and decreased pressure. "While climbing a mountain in Peru," says he, "I was suddenly seized and surprised by a distemper so deathly and so strange that I well nigh dropped from my saddle to the ground. - - - Happening then to be alone with an Indian, whom I begged to assist me in keeping astride of my horse, I was taken with such a paroxysm of sobbing and vomiting that I thought I would surely die. - - - It only lasted for three or four hours until we reached a much lower region. - - - And these injurious effects are felt not only by men, but also by beasts." - - -

And further: "I am inclined to believe that the air in that region is so subtle and delicate that it is not adapted for human breathing which requires it to be coarser and more temperate." The correctness of these last words, uttered three hundred years before the time of Priestley and Lavoisier, is striking. The air at high elevations is indeed too rare, too subtle for superior beings to breathe. The distemper described by Acosta is that which, in different localities, is called *pûna*, *soroche*, *veta*, mountain or balloon sickness. More recent descriptions of it have been given by Tschudi, Lortet, and many others; all have observed the dizziness, the vomiting, the anxiety, the fainting by which it is characterized. Certain experiments by Lortet and by Chauveau and others have shown that respiration is abated and at the same time quickened. There have been noted intense muscular pain, and circulatory and nervous disorders which end in paralysis and death, if, as happened in the disaster of the "Zenith," these disorders occur simultaneously for some time.

Without describing the opinions held at various times in regard to the cause of these dreadful accidents, we shall confine ourselves to recalling the explanation recently given by Paul Bert and other physiologists. It is a very simple one; the deadly disorders are brought about by a diminution of the tension of oxygen, the diminution growing out of the relative rarefaction of that gas, the air being more rarified, more dilated, as it were, in elevated than in intermediate regions. In truth, Paul Bert's researches show that in these cases the diminution of pressure kills organisms not by its mechanical effect, but by a chemical effect, by the scarcity of oxygen, by producing *anoxyhemia*, or deficiency of oxygen in the blood. An animal immersed in a rarified atmosphere dies from the same cause as an animal breathing in a close non-ventilated space; both die for lack of oxygen. In the case of fish living in great depths, when they come too near the surface the gases which exists in their bodies in a state of powerful tension easily burst the tissues asunder as soon as the exterior pressure becomes notably less than the interior. This same thing sometimes happens to man, as we shall see presently.

The case we have just examined is that of an animal, or man, passing gradually from a low or intermediate level to a very high one. We have now to consider another case, that in which the transition from a normal or high pressure to a low one takes place suddenly. Instances of this occur when a man working under a pressure of 3 or 4 atmospheres in the caisson of a bridge pier suddenly returns to the surface; or when a diver is too hasty in coming out of the water, or when an aeronaut is accidentally lifted to high elevations by a balloon overcharged with gas. In cases when pressure is rapidly diminished death is known to supervene in a very short time. An animal placed in a bell glass in which the pressure, normal at first, is suddenly lowered by means of a few strokes of the air-pump, will be prostrated and die forthwith, although the final pressure may not be at all incompatible with life, if

the diminution be brought on by degrees. We see here some difference between the phenomena presented and those which occur in the case of gradual reduction of pressure, a difference which is explained when we examine the bodies of the victims by the fact that there are found under the skin, in the tissues and in the vessels, free gases, a condition that never occurs normally. The cause of death is revealed by these gases. Blood and all the tissues constantly contain, as we know, gases such as oxygen, nitrogen, etc., that are either free or combined with the globules, and in proportions which vary with the external pressure; that is, according to the degree of tension of the same gases in the atmosphere. If the barometric pressure gradually decreases, the tension of the gases in the organism decreases in the same manner. The gases gradually pass from the blood into the atmosphere without causing any disorder. But if the rarefaction is sudden, this gradual operation can not be accomplished, and the result is that the gases in the blood and tissues, being in contact with an atmosphere in which the pressure is much less than in the blood, are suddenly released in the shape of bubbles and the circulation is paralyzed. To avoid accidents of this kind men working in compressed air are always cautioned against a too sudden return to the open air. They have little to fear from the compressed air; all the danger lies in the removal of this compression. "We pay as we go out," as they put it in their picturesque language.

So much for a decrease of pressure, whether rapid or slow. In the case of slow depression the harm is done by a deficiency of oxygen, by anoxyhemia, and it is for this reason that aeronauts take oxygen along, so as to counteract the rarity of the atmosphere at great heights. In the case of rapid depression, whether the transition be from a high to an intermediate or normal pressure, or from an intermediate to a low pressure, the trouble arises from another cause, of a mechanical nature, from the swift release of the gases contained in the tissues, and especially in the blood, thereby producing a stoppage of the circulation. The presence of free air or of any other gas in the vessels is known to quickly produce paralysis of the heart. Whenever the sudden change of pressure is from high to intermediate, anoxyhemia does not intervene and the mechanical cause prevails. If the intermediate pressure changes to a low pressure, anoxyhemia takes place if the change is slow. Both anoxyhemia and disengagement of gases occur if the change is sudden.

Let us now consider the cases in which the pressure is increased That which takes place in the depths of mines need not be discussed, for the increase is insignificant, and its physiological effects may be left out of account. The influence of an increased pressure is best studied as affecting divers, for instance, and men engaged in sinking bridge piers. These men work in a medium where the barometric pressure is high, much higher than in the deepest mines, for the reason that the

pressure of water, which is much denser than air, must be offset by a considerable compression of air, equal to 3 or 4 atmospheres. When that compression is moderate the disorders are slight, and are confined to a buzzing sensation in the ears, bleeding of the nose, and benumbing of the limbs; but breathing becomes slower and the pulse more laggard. In some cases the nervous system exhibits abnormal excitement, similar to that produced by intoxication. It is quite natural to infer that these accidents are the result of an increase in the tension of carbonic acid and indeed that gas does produce the mischief so long as the compression does not go beyond certain limits, for it accumulates in the organism, and, as a natural consequence, suffocates and poisons it. But if heavy pressures are brought into play, as was done by Paul Bert, a very uncommon and quite different result is reached. That lamented physiologist, laboring under the impression that he would retard the fatal effect of compression, charged the air with a large proportion of oxygen for the purpose of combatting the poisonous action of carbonic acid, and was not a little surprised to find that his attempts only resulted in precipitating the catastrophe. By analyzing the phenomena he found that under considerable pressure, over 6 atmospheres, the oxygen of air, by acquiring a very strong tension, becomes a poison in the same manner as it does for an animal breathing under normal pressure in a medium abounding in that gas. And the evidence of the injurious effects of oxygen is furnished by the fact that an animal can easily stand a pressure of 20 atmospheres if the air is poor in oxygen, if that gas, being more rare, attains a tension but little higher than that which it possesses in the normal air under ordinary pressure. When under excessive tension, or in too great abundance, which amounts to the same thing, oxygen always proves to be a poison of the most dangerous kind, and it is for this reason that animals and men die in a normal atmospheric medium so soon as the pressure increases beyond certain limits. Whether the compression be swift or slow, it is the excess of oxygen that is fatal. If we leave out of consideration all cases in which the changes of pressure are rapid, and in which, as when the pressure is suddenly lessened, a purely mechanical agent intervenes, we shall generally find that the action of gradual variations is not of a physical nature, but exclusively a chemical one, induced by putting the organism in contact with air that is either too rich or too poor in oxygen.

It is proper to add that habit, here as elsewhere, plays an important part.* For instance, Indians and animals in the Cordilleras are proof against the mountain sickness that attacks travellers, and animals living in great depths undergo pressures that no being on land or in shallow

* Recent investigations conducted by Messrs. Müntz and Regnard have proved that when carried to elevated regions or subjected for some time to experimental rarefaction, a person acquires the power of absorbing larger quantities of oxygen. This explains the beneficial effect of a sojourn in the mountains.

waters could stand. This however adds no new phase to the question. There are for all, without exception, certain increases or decreases of pressure that prove fatal, and from a general standpoint there is no importance in the fact that their adaptations are different, for the differences are in degree, not in kind, and the nature of the phenomena remains unchanged.

We are then justified in saying that while the influence exerted by variations of pressure over animate life is apparently mechanical it is actually a chemical one. Does this also apply to the action of atmospheric movements? If we leave out of consideration the effect on the chemical composition of air had by the winds and other atmospheric motions in promoting a diffusion of such gases as are produced in abundance at various places, together with the regulating action of the ocean, we shall satisfy ourselves that the influence of these movements is purely physical. Looking at this question from the particular point of view of this discussion, these movements must be considered as regulators of temperature and as propagators of certain forms of life. They must of necessity be the former, since winds are chiefly caused by unequal heating of the ground and air in different places, and, if there were no wind, the temperature would soon become unbearable and noxious to life. Without winds, the water from the ocean would not be carried overland by the clouds, and great droughts would follow. Without winds, air vitiated by local causes would remain in that condition; impure gases from natural or artificial sources would disperse but slowly. Wind is the cleaner, the sweeper of the air; it drives it, stirs it, mixes it, transports it over every land and every sea, and insures a general distribution in the whole atmosphere of such elements as are produced in superabundance at any one point. It maintains the purity of the atmosphere, or at least its homogeneous composition, and aids in preventing excessive inequality of temperature.

Atmospheric movements also assist in regulating the individual temperature of men and homeothermic animals. Wind keeps air from becoming saturated with moisture. We all know how oppressive heat is in a warm and moist atmosphere when perspiration is not easily evaporated, and on the other hand, absolutely dry air is not without its inconveniences and irritates the lungs. By distributing in every part of the atmosphere the moisture which is plentifully produced in some of its parts, wind does living beings a great service. It is also useful in promoting the dispersion of a number of insects and vegetables, which it carries afar, beyond the sea, to distant islands and continents. But it also is objectionable, in that it scatters at the same time the pathogenic microbes and spreads diseases of which they are the cause. I shall not now dwell on this point, for it will claim our attention later. It is enough now to note the simultaneous influence for good and evil which is exercised by atmospheric movements, the nature of such influence being entirely due to that of the objects transported by them.

IV.—SECONDARY INGREDIENTS OF THE ATMOSPHERE.

We have now examined the relationship of animate life with the chemical composition of air, with its pressure and its movements. It remains for us to consider the relationship with air contents. There are many accidental, secondary, inconstant elements in air. Some are gaseous, of natural or artificial origin, such as carbonic oxide, carburetted hydrogen, and hundreds of others. We shall say nothing of these here, for after all every substance known in chemistry may, according to locality and circumstances, be found in air, and their presence is always accidental. Those of which we propose to speak are regular although unessential elements of air. Among these we shall especially examine vaporized water or moisture and certain solid substances, animate and inanimate, not mentioning for the present pulverized minerals cast forth by volcanoes, produced by industries, or drawn from the earth.

Moisture is at all times disseminated through the atmosphere in the shape of clouds or fogs and also in the form of invisible vapor. It is concerning the latter that we propose especially to speak. It has a dual origin. One part is supplied through evaporation by the water contained in the seas, the rivers, and the ground. This evaporation is determined by both the temperature of the air and the quantity of moisture already contained in it. Another part comes from living beings, from transpiration through the pulmonary and cutaneous surfaces of animals and from evaporation normally going on from the leaves of plants. This production of watery vapor by living beings is very variable and is considerably modified by external conditions. An animal or man breathing in very dry air will produce a much greater quantity of vapor, for the breath when exhaled is saturated with it; but if very moist air be inhaled the production is very small and merely restores to the atmosphere the moisture taken from it. All mankind produces about 15,000,000,000 kilograms of water in twenty-four hours, but this is much more a restitution than a creation. In like manner plants add but little to the supply of moisture in the air if it already abounds; but in dry air they emit enormous quantities. It has been possible to estimate, for instance, that a grove of 500 full-grown, healthy trees emits nearly 4,000 tons of moisture in twelve hours of daylight. Vegetal transpiration is less by night and barely equals one fifth of the evaporation by day. This single illustration will suffice to show how great is the production of moisture by vegetation. Now, if one stops to consider that in the United States, for instance, the surface area of foliage is, according to Mr. J. M. Anders, at least four times as great as that of the land, one will realize how important a part is filled by vegetation in connection with the question we are now studying, and will not wonder that certain physicists have estimated the quantity of water in the form of vapor contained in the atmosphere at 72 thousand billions of tons or cubic meters.

This moisture which is diffused in air in greatly variable proportions,

depending on locality, time, and many other conditions which I shall not enumerate, is of considerable importance with regard to life. Air, when too dry, iritates the respiratory organs; when too moist it impedes transpiration, or rather checks its beneficent effects. Vaporized moisture performs still another function of greater importance. It interposes between the ground and the sky a beneficent screen which during the day mitigates the sun's heat by absorbing a portion of the rays and prevents it from scorching the ground and vegetation; and at night, inversely, it precludes excessive cooling by radiation. In fine, moisture allows the luminous rays of heat to pass, but absorbs a great portion of the dark rays, whether they come from the sun, the earth, or any other source. The experiments of Tyndall, and especially of Pouillet, have proved that air, through the medium of its moisture, absorbs nearly one-fourth of the solar heat, and allows only three-fourths of it to reach the earth. If it were not for this screen, this strainer, our summer days would be at the same time much warmer and much colder, as is the temperature on high peaks or that which is encountered at high altitudes in balloon ascensions. For the higher the altitude the thinner the layer of vaporized water lying between the sun and the observer, and under such circumstances the sun is scorching. Its rays, meeting less obstruction, overheat everything, and on the other hand the surrounding air is extremely cold, since it contains but little moisture and absorbs very little heat. So that if there were no moisture, our summer days would be torrid and at the same time icy cold; we would be scorched by the sun, but the air would remain cold, and in the shade very low temperatures would be occasioned by the great radiation.

At night moisture moderates radiation. The earth, heated during the day, tends during the night to relinquish that heat and to return it to the interplanetary spaces. This radiation is considerable when the sky is very clear and the weather very dry; a clear night is colder than a cloudy one; it is colder on summits having but a thin layer of atmosphere and vaporized water above than in low lands, over which is spread a thicker atmospheric layer. Radiation is a phenomenon that can not be avoided considering that the temperature prevailing in celestial space is infinitely low, probably less than 100° below zero; but it increases as the air becomes drier, and contains less moisture by which the dark heat rays emitted by the earth can be absorbed. In the absence of moisture, the sun would no sooner set than considerable refrigeration would take place, as it does on high mountains, on elevated table lands, in Thibet for instance, or even in deserts like Sahara, where the atmosphere is very dry; and such refrigeration would prove very injurious and even fatal to many animals and plants. Moisture, therefore, mitigates the heat of day and the cold of night; it establishes some uniformity where extremes unfavorable to life would otherwise alternate. Let us also point to the part it fills in preventing total darkness during the night by receiving light in altitudes which the solar rays

still penetrate after the orb has left us. It may be said that many forms of animal and vegetable life would disappear but for the vaporized water in the air; this will be enough to convey an idea of its importance.

The action of the numerous solid substances found in the atmosphere is as varied as their nature. Physically pure air is, in fact, a myth, and can only be obtained in laboratories by using certain precautions. Even at the highest altitudes in which the number of air-microbes is small and where they are in most cases actually absent, as are also vegetable or animal particles, there are always to be found mineral dusts, very finely pulverized, to be sure, some of which comes from the ashes ejected by volcanoes or from the soil itself, and some from the infinitesimal fragments of aerolites that have crossed our atmosphere. We can easily perceive these dusts with the naked eye on looking at a ray of the sun when it strikes across a room. But if we wish to thoroughly analyze them, we must resort to the microscope and the aeroscope. We shall then find the most diverse elements; desiccated animalculæ, worms, rotifers, etc., vibriones, infusoria, fragments of insects, of wool, scales from butterflies' wings, hairs, feathers, vegetable fibers, mushroom spores, particles of pollen, of flour, of dust from the soil, and finally microbes. But little interest attaches to many of these fragments considered from the present standpoint, although it is an interesting fact to know that pulverized matter of volcanic origin, like that which was recently cast off by Krakatoa, can remain for years floating in the air at very high altitudes and, by the action of the winds, move around the earth and produce the luminous phenomena of so great interest that have been noticed by the physicists of every country and that we all saw for ourselves a few years ago. With regard to life, a matter of interest is the presence of grains of pollen which being carried to great distances by the wind may eventually fecundate flowers of the same species; the presence of the spores of cryptograms which promote the dispersion of that group; again, the presence of numerous seeds so constructed as to be easily transported by air, thus promoting their dissemination. These seeds are very light and provided with appendices that enable them to float in air for a long time and to travel over immense distances, and finally to be sown far away and thus expand the domain and habitat of the species from which they sprang. Instances of this kind are plentiful and it were idle to attempt a longer recital. Another matter of interest is the presence of microbes. Many among them are innocuous, but there are also some that are deadly. Cast off into the air by patients affected by tuberculosis, smallpox, scarlet fever, measles, diphtheria, or any microbian disease, taken from the ground on which contaminated matter has been thrown, these microbes are lifted and transported by the air and scattered in every direction, near and far, in a trail of death. They are particularly numerous in inhabited places. At Montsouris, M. Miquel found from 30 to 770 per cubic meter, according to wind, season, etc., 5,500 in the Rue de Rivoli, from 40 to 80,000 in hos-

pital wards, whilst at 7,000 meters above the sea and at a distance from land none at all are found. These figures will sufficiently indicate how dangerous an agent air may be under certain circumstances and how it transmits death.

As we have seen, air carries at once both life and death. Each one of its elements is indispensable to life, and each one is a death-dealing agent according to conditions and doses. That element which appears to be the best supporter of life becomes at times a dangerous poison; while the element that is apparently useless and most noxious is shown by analysis to be one of the essential foundations of life. The conclusion must be that not one of them could disappear or change its condition without at once turning the earth into a naked and barren globe, deprived of all animate life.

On closer examination another fact is disclosed to us. In the very felicitous words of J. B. Dumas, all living beings are nothing but condensed air. The plants owe their existence to air, and animals could not exist without plants. The elements of plants are themselves air, and as animals depend on plants, the connection is close, intimate, and direct; man is condensed air. And since throughout the centuries during which human-kind has existed, that same air has done nothing but pass without intermission through the bodies of our ancestors, forming a part of them for a time and then becoming disengaged, *our* present body is composed of the same elements as was that of our forefathers. Our substance is the same as theirs. And that substance which is also that of the plants of yore, is incessantly moving through space in a ceaseless tide. To-day or to-morrow, a flower or a fruit, it will unite at one time with the sluggish organism of a mollusk, at another with the brain of a Descartes, a Pascal, a Joan of Arc, or a Shakespeare. It never stops; its cycle, of which no human eye ever saw the beginning and no human mind can imagine the end, seems to be infinite; alternating from life to death, as old as the world and, withal, eternally young, it would, if it only were conscious, have exhausted all the joy and all the grief that life can afford and experienced all the emotions, the most noble and the basest.

The air that lately gently fanned our faces is the sum total of all life that has been, it is a myriad of lives: it is those who preceded us; it is the dear dead for whom we mourn; it is now a part of ourselves, to-morrow it will proceed on its way, going through incessant metamorphoses, passing from one organism to another without choice or favor, until the time comes when our planet shall die and the substance of all that was life shall return to the cold earth, a gigantic grave that will revolve in silence and desolation through the unfathomable depths of the darkened heavens.

And then? Science returns no answer. In the book of nature which is spread before us and which we eagerly scan for a key to the future, two pages are missing, the two very pages that we care most for, the first and the last.

DEEP-SEA DEPOSITS.*

By A. DAUBRÉE.

The expedition of the *Challenger* will rank as among the most famous ever undertaken in the interests of science. The new and weighty facts which the expedition disclosed, as well as their thorough investigation, are admirably set forth in the published reports.

For a long time naturalists believed that the existence of any life in the great sea depths was rendered impossible by the enormous pressure and the total absence of light.

Although Capt. John Ross and Lieut. (since General) Sabine declared, in 1829, that in exploring Baffin Bay living animals had been drawn from a depth of more than 1,800 meters, this assertion as well as similar ones which came from no less reliable sources, did not meet the credit which they deserved. Not until 1860, when Dr. Wallich returned from an expedition to Greenland and Newfoundland, was justice done to these assertions which ran counter to current theory.

About the same time, as early as 1858, the laying of a sub-marine telegraphic cable between Europe and America led numerous and systematic soundings to be taken. These brought new ideas into biology and geology, and the importance of a thorough exploration of the great ocean basins began to be better understood.

An observation made by Mr. Alphonse Milne-Edwards upon the fragments of a sub-marine cable intended to unite Algeria and Sardinia, which had remained at a depth of 2,000 to 2,200 meters, should be mentioned here as of substantive value on the question in point. He noted coral and shells which had evidently attached themselves to this cable at their first growth, as several of them had taken its exact shape and were still alive when taken from the water.

The impulse thus given, scientists of various nationalities, from Norway, England, and the United States began to organize expeditions for the special purpose of exploring the deeper regions of the sea. Michael Sars on the coast of Norway, Louis Agassiz and Count Pourtalès in the Atlantic (1867 to 1869 and again in 1872), published results of very

*A review of work of the Challenger Expedition. (Translated from *Journal des Savants*, December, 1892, pp. 733–743, January, 1893, pp. 37–54.)

great interest, and equally remarkable results were reached by Wyville Thomson and Carpenter who explored first in the neighborhood of the Faroe Islands and afterwards in the Mediterranean.

Perceiving in the data already acquired the promise of future discoveries, several English scientists conceived the project of a voyage around the world for this special object, a vast scheme and one to which they devoted all their efforts. The admiralty, after conferring with the Royal Society, put at their disposal a screw steam corvet of 1,200 horse power, the *Challenger*, which swept with its dredge the bottom of all oceans, and whose name will last forever in the history of science. The scientific commission on board was provided with machines, laboratories, and every resource that could be desired, and was presided over by Sir Wyville Thomson, who, as we have seen, had previously undertaken similar explorations.

The expedition of the *Challenger*, like several of those which preceded it, was specially designed to search for living things at great depths, but it was also proposed in the programme to study with care, by soundings and with the dredge, the forms and the mineral constitution of the great ocean bottoms.

The relatively small quantity of sediments heretofore collected in previous cruises, and the very limited areas to which the investigations had been confined, did not permit the statement of general laws concerning the distribution of the deposits formed in the abysses of the sea. Their geological importance, however, was perceived from the early researches, and they thus opened the way for special explorations in this new realm.

The voyage of the *Challenger* lasted for three years and a half, from December 7, 1872, to the 27th of May, 1876. It was made under the command of Sir George S. Nares, who in January, 1875, left the ship to the command of Capt. Frank Thomson, in order that he himself might direct the *Alert* and the *Discovery* to the Arctic seas.

A publication composed of thirty-nine large volumes has acquainted us with the numerous conquests which science owes to this memorable enterprise, specially in zoology, botany, physics, and chemistry. The magnificence of the edition, the beauty of the maps and of the plates, many of which are colored, leave nothing to be desired. The last volume,* under the title of *Deep-Sea Deposits*, describes the nature of the bed of the seas at their greatest depths. It is a collection of information for the most part entirely new, and the things brought to light are of a nature which greatly stimulates the imagination.

If we consider how rich is the array of observations contained in this volume, it will not seem astonishing that its authors have made us

*Report on the scientific results of the voyage of H. M. S. *Challenger*. *Deep-Sea Deposits*, by John Murray and Rev. A. F. Renard. Published by order of the English Government, London, 1891. Large quarto, (xxix and 396 pages, with 43 maps, 22 diagrams, and 29 lithographed plates.)

wait more than sixteen years for it. They had however already partially satisfied the impatience of the world of learning by publishing the principal results as separate memoirs.

Mr. John Murray, on board the exploring ship, had the duty of collecting, examining, preserving, and classifying all the specimens brought to the surface by soundings or the dredge, and of making all the notes relating to their derivation. Since his return to England this scientist has devoted himself entirely to the examination of this large quantity of material.

In 1878 Sir Wyville Thomson* and Mr. Murray were happily led to ask the collaboration of the eminent Belgian petrologist, the Abbé Renard, professor at the University of Ghent, whose microscopic investigations of rocks had already contributed much to the progress of science, and had secured him special authority in that study.

Among the difficulties presented to these gentlemen were the tenuity of the dusts, often extreme, the almost constant fragmentary form of the particles, and the change in their nature, effected by the chemical action of the sea.

In another portion of the work Mr. Renard had given a description of the rocks, mostly of a volcanic nature, collected in the Oceanic Islands, and had determined with precision their crystalline elements.† These rocks were to serve as terms of comparison with the débris of the same nature which occupies so large a space in the great ocean depths.

In addition to the collections of the *Challenger*, Messrs. Murray and Renard had at their disposal the sediments gathered by several other English expeditions. Prof. Mohn, of Christiana, gave them the deposits dredged in the North Atlantic by the Norwegian expedition, whose beautiful and important publications are known to all naturalists. Besides these, the Coast Survey of the United States and Mr. Alexander Agassiz consigned to them a series of specimens of soundings, obtained by various American ships. Thus, the material gathered by almost all the sub-marine explorations, were used in the investigations, the results of which we are about to consider.

The two great French expeditions, so well known from their splendid discoveries in the deep seas, are not spoken of in this article, because they were of a subsequent date to that of the *Challenger* and because their purpose was essentially zoological. That of the *Travailleur* was from 1880 to 1882, and that of the *Talisman* in 1883. Of the studies made by Albert First, sovereign prince of Monaco, the first date from 1885.

Before noting the discoveries relative to the great depths of the sea, it is well to recall in a succinct manner the knowledge already possessed.

* Sir Wyville Thomson died in 1882.

†Report on the Petrology of Oceanic Islands, 1889; 180 pages, 7 maps, and numerous diagrams.

after innumerable examinations, of marine sediments in comparatively shallow regions, bordering continents and islands, and which we shall designate here under the name of marginal.

MARGINAL SEDIMENTS OF THE SEA.

The configuration of the bottom of the ocean had drawn the attention of the ancients, and their observations on this subject, as upon many others, proves the sagacity of the Greek philosophers. In a special work Posidonius adopts the opinion expressed more than a century before by the great geometrician, astronomer, and geographer, Eratosthenes, that the earth, save for accidents which are imperceptible in such dimensions, is spherical.*

After having studied the three voyages of Eudoxus of Cyzique, Posidonius concludes that the ocean surrounds the inhabitable land, and that a ship leaving the west with Eurus at the stern would arrive in India after traversing a distance estimated by him at 70,000 stadia.† The same author states that the depth of the sea near Sardinia reaches nearly 1,000 *orgyes*, or Greek fathoms. (About 1850^{m}.) This is probably the oldest notice of a deep sea sounding, and it is to be regretted that the process by which it was obtained is not known.

After the immortal discoveries of Christopher Columbus, of Vasco de Gama, and Magellan, had added a hemisphere to the map of the world, the knowledge of the sphericity of the earth, of the existence of the antipodes, gave rise to many new ideas. Magellan tried in his voyage across the Pacific to measure its depth, but in vain. Up to that time, that is to say, until the middle of the sixteenth century, a depth greater than 400 meters had not been sounded.

It is but just to recall here the name of Buache,‡ member of the Academy of Sciences, who made in 1737 a first attempt to represent the bed of the sea by the aid of contours. In a memoir published in 1752 he says: "The use I have made of soundings, which no one before myself had ever employed to represent the bottom of the sea, seems to me very proper to show in an obvious manner the slopes or declivities of the coasts, and carries us by degrees to the bed of the basins of the sea."

The nature of the material constituting the bed of the sea, Herodotus tells us had also been the subject of his meditations.

Strabo, with the penetration and certainty of his judgment,§ remarks that the sea continues to receive without interruption the alluvium of

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*Strabo: *Geography.* Translation of Mr. Tardieu; vol. I, p. 85.

† Same work, vol. I, p. 92.

‡ Essay of Physical Geography, in which general views are stated upou the frame-work of the globe, composed of chains of mountains which traverse both seas and lands, with some special considerations on the various basins of the sea and upon its interior configuration. (*History of the Academy of Sciences*, 1752, p. 399.)

§ Strabo's *Geography*, translation above quoted, p. 92.

the rivers and tends thus to fill itself up. He considers however that the sediments of the rivers, instead of extending over all the ocean bottom, are deposited near the mouth. Strabo attributes to the movement of the sea, to its *respiration*, as it was then called, the impossibility for the sediment to extend a great distance from the shore. The wave, says he, expels all foreign bodies from its bosom, producing thus a *purification*. On the other hand, the presence of deposits of shells in the interior of continents had not remained unperceived, and this important observation leads Strabo to say that "the sea has, during periods more or less long, covered, then left dry, by withdrawing itself, a goodly portion of the continents."*

This different point of view may give a notion of ancient deposits of the sea, and consequently serve to clear up the history of present deposits.

The origin of organized fossil bodies, thus vaguely seen by several philosophers of antiquity, was fully confirmed in the fifteenth and sixteenth centuries. By a flash of genius, Leonardo da Vinci saw the present sediment of the seas in the shell layers of the Apennines in which, as engineer, he was making excavations. Bernard Palissy, on his side, without knowledge of this conclusion, was himself led to it through his observations in Saintonge. Simple potter as he was, he offered to prove against all the doctors of the Sorbonne that fossils are the débris of organisms which have lived in the place where they are found, "while the rocks were nothing but water and mud, which became petrified after the water dried up." No one is ignorant how this resemblance has been since then clearly recognized and accepted in regard to the series of strata which succeed each other in enormous thicknesses in the interior of the continents. Thus for a long time we have been compelled to admit that fossiliferous strata result from the sediment formed in ancient epochs of the history of the globe, during which time the sea covered vast regions which have now emerged.

The deposits which we see to-day forming in the ocean are the continuation of those which have accumulated there through the ages since the epoch when the mass of water condensed upon our globe and surrounded it with a liquid envelope.

The rocks continually attacked by atmospheric agencies are reduced little by little to small fragments. The chemical action of the air, the physical part performed by the water, the physiological influence of plants concur to produce their more or less complete disintegration. Continents, upon the surface of which this work is going on everywhere, are thus covered with the débris of the rocks which running water can easily take hold of. Whether such waters are rivulets, torrents, streams, or rivers, they seize, carry off, and drift toward the ocean the mineral particles. This happens even with the most tenacious rocks, such as granite. This detritus is partially arrested in the

* Work cited, p. 86.

course of rivers, hence the accumulations of ooze, sand, and gravel, well known under the name of alluvium, which border different portions of their course. and the even and level surface of which recall the covering of water which has spread them out.

At the mouth of the rivers, in the sea as in lakes, the retard in velocity of the waters effects the operation in the most marked manner; therefore plains of alluvium are specially developed in these places.

The alluvium is not restricted to this border: it is formed in the open sea by the action of a transportation effected by waves, tides, and currents more or less constant. These motions affect also the deposits which come from the ocean coasts. We learn this from the marine maps which give, together with the ocean depths, the nature also of its bottom as it has been determined by soundings. Examination of these maps shows that the deposits in question are spread out usually in flat form and constitute the real submarine plains, comparable with the slimy and even plains existing at the mouth of rivers. Such are, for example, the bottom of the English Channel and the deposits which border France in the ocean.

Thus the sea may be considered as an immense work-room of trituration, of transportation and deposition. It produces on a large scale the same effect that takes place over a distance of a few kilometers in the bed of a torrent. Deposition is finally effected in the relatively calm regions of the ocean basin.

In this incessant work of demolition the liquid waters have also very active co-laborers whose importance is not recognized in temperate countries such as we dwell in. They are the masses of ice which accumulate in the valleys around the mountainous masses covered with perpetual snow. In spite of their apparent immobility, these glaciers, of so imposing and magnificent an aspect, have a descending movement, slow and continuous. Thus they constitute, on account of their solid state and their enormous weight, even more than liquid water, most energetic agents of wear and transportation. In the region not far from the pole, the part performed by glacial torrents and floating ice permeated with fine detritus throughout their mass is specially recognizable

The Norwegian expedition, the labors of which have been published under the direction of the eminent professor, Mohn,* has very clearly determined the facts in question, so far as concerns Spitzbergen, Iceland, and Greenland. The ooze from the glacial trituration extends over the whole bottom of the North Atlantic, and seems to form its chief sediment as far as 36° of latitude. The presence of similar deposits has been ascertained along the coast of North America, and in the Southern Hemisphere as far as about 40°.

* *Den Norske Nordhouse Expedition*, 1876, 1878, 9th ed., p. 70.

Mr. Nordenskiöld, in his second expedition to Greenland, plainly recognized also the abundance of dusts from the friction of the glaciers on their bottom. When this very fine clay has been dried by the sun, it is put in motion by the least breeze, and the air is filled far around with clouds of dust, so that the rocks and plants are covered with a sort of grayish powder, which gives a somber appearance to the whole country. The eminent traveller saw, in transportations of this nature, not only one of the elements of marine sediments, but also the probable origin of the diluvial ooze, known under the name of *loess*, in conformity with the views of Mr. Richthofen.*

It must also be remarked that the currents of the atmosphere carry across the widest seas terrestrial dust of all kinds, volcanic and other. The deposits of the ocean find active collaboration in this aerial transportation.

Marine sediments are not composed merely of mineral débris, more or less fine, pebbles, sands, and ooze. Solid remains which mollusks and other inhabitants of the sea leave after death, are associated with this débris in large numbers, and are sometimes deposited in predominant proportion. Such remains often lose their characteristic forms in consequence of dissolving chemical action so as to augment the mass of deposits apparently inorganic.

It is thus that these various accumulations gradually come to constitute around continents a sort of belt which constantly increases.†

In co-ordinating all that was known of these marginal deposits, the only ones which had then been studied, Delesse published thirty years ago a lithological study of the sea bottom. The hydrographic maps made by naval officers and engineers served as the basis for his works.‡ In regard to the seas bordering France, which were the principal object of the author's studies, he himself examined all the specimens collected both on the shores and farther out. Tables of hundreds of deposits show their exact derivation, their physical, mineralogical, and organic characteristics,§ and also their chemical composition. An atlas annexed to the text gives three lithological maps, very skillfully executed, representing, one, the seas of France, another the seas of Europe, and the third the seas of North America.

In certain regions of the shore the nature of the sea bottom has been so completely studied in all its particulars that an idea almost as exact

* *The Second Swedish Expedition to Greenland.* Trans. by Charles Rabot, 1888, pp. 247 and 248.

†The width of this belt is calculated at an average of 250 kilometers; it extends often to 600 and 700 kilometers, for example on the coast of Brazil, opposite the Amazon.

‡Lithology of the Seas of France and of the principal seas of the Globe. Paris, 1872.

§ Dr. Fischer, who has studied the organic character of the deposits, has already recognized, among the interesting results, the importance of the bryozoa and of the foraminifera as they occur in many of the ancient sedimentary layers.

may be formed of it as if the bottom were not concealed from us by the covering of water above. Such is specially the case for the Straits of Dover.

Thomé de Gamond, who was the initiator of the proposal to make a tunnel across the English Channel, saw the necessity of first making a study of the submarine ground.* Although he had only his own personal resources and was unprovided with any diving apparatus, the projector of this attempt, with a boldness which proves his excessive enthusiasm for his idea, did not hesitate to launch himself into the sea in a strange apparatus of his own invention. After diving with great intrepidity three times in one day, he managed to acquire useful data for a distance of a kilometer and a half from the shore.

Later, when the same problem came to be studied in a more exact manner, the necessity of a basis of absolutely exact data was perceived. First of all, it was necessary to determine upon the sea bottom the continuity of the different strata of the cretaceous formation, which appear very much alike in both the French and English cliffs on both sides of the channel. A commission composed of Messrs. Larousse, Potier, and Lapparent made 7,000 soundings, of which nearly 3,000 returned determinable specimens. Thus, thanks to geology, the enterprise which at first appeared so doubtful, rested henceforth upon positive facts accurately established. It was learned that the boring could be continuously carried on in a layer of so-called *grey chalk* soft enough to be easily worked, and sufficiently impervious not to allow the penetration of water.

Lastly, and quite recently, after having been forced to abandon a sub-marine passage, it was suggested to build a bridge across the straits of Dover. The bottom of the channel was again made the object of numerous careful investigations. This time the nature of the ground upon which the piles would rest had particularly to be known. The exploration made in 1890 by Mr. J. Renault, hydrographic engineer, furnished the data, and in addition to the usual material for sounding and dredging, he constructed special apparatus for drilling which was used. Four hundred drillings were made, and not fewer than 3,000 soundings.

The marginal sediments of which we have just spoken, and to which Messrs. Murray and Renard give the name *terrigenous*, extend along the continents, over a zone which, measured from the shore, occupy the variable dimensions of from 100 to 500 kilometers. They also form the bottom of inland seas, such as the Mediterranean, the seas of North China, of Japan, and of the Antilles.

Besides the marginal deposits that we have just mentioned, and the deposits of the great depths which we are about to consider, there

* Thomé de Gamond. *Study for a proposed submarine tunnel between England and France, uniting the railways of the two countries without breaking bulk, by the line of Grinez to Eastware, with map of proposed direction and the profile of the tunnel crossing the geological diagram of the submerged pier.* 4to. Paris, 1857.

exist some which form, as it were, an intermediary between them and to which the authors give the name *littoral deep sea deposits.*

Terrigenous débris still form the principal part of these deposits. In fact, among the products carried off from terra firma, there are some which remain suspended long enough in the air or in the sea to be transported at last into the domain of the deep seas. It is thus that particles of quartz and of other rocks, the continental origin of which is easily recognized, have been met with at a depth of 7,000 meters.

The blue muds must be specially noted: They are characterized by a slate color which comes from the presence of organic matter in a state of decomposition. They often exhale an odor of sulphuretted hydrogen and in that case they are mixed with sulphide of iron. This often happens in the vicinity of a continent where large rivers bring in suspension reducing organic substances. Fragments of minerals such as quartz, mica, and feldspar, in very fine grains of the diameter of half a millimeter at most, often appear in them.

ABYSSAL SEA DEPOSITS.

Until recent times no ocean sediments had been explored, except those formed as we have just seen, in the vicinity of continents and islands, and which border them, like belts usually of small width compared with the vast dimensions of the sea.

Beyond a depth of 500 or 600 meters the waves and currents seem no longer to exercise an erosive influence. The agitation of the water and the mechanical action witnessed in the vicinity of land are not felt in the abysses unless in exceptional cases. It appears from the thermometric observation of the *Challenger*, it is true, that the cold waters have a motion at the great ocean bottoms from the poles toward the equator, but the motion is very slow and could exercise but slight influence upon the distribution of marine sediment.

Thousands of kilometers may be sailed over in certain directions across the Atlantic and the Pacific without seeing any land above the surface, but finding everywhere depths of several thousands of meters. What takes place in these vast regions where the waves which toss the surface can not exercise a mechanical action on any solid mass? This could not be known or even surmised before many soundings, made over large areas, had furnished their contingent of observations. To bring up specimens of the bottom from several thousand meters below the surface was a difficult operation, and to do it successfully ingenious and powerful apparatus, skillfully manipulated, was needed. The expedition of the *Challenger* surmounted all obstacles.

The bottom deposits of the great oceanic basins which differ much from the marginal, have received the name pelagic. We prefer to use here the term *abyssal*, which expresses with greater precision the great depth which constitutes their essential character. - - -

However worthy of interest the question of life in the abysses of the sea may be, we shall pass it by here, to study the strictly mineral substances with which these organized vestiges are usually associated.

The thing to be noted before all others, in the central parts of the great oceanic basins, is the gradual disappearance of terrigenous deposits, which are replaced by volcanic débris.

This contrast had been perceived as early as 1856, when the soundings were made in the North Atlantic for laying the telegraphic cable between Ireland and Newfoundland. The idea which had at first presented itself was that the scoriaceous silicates brought to the surface might be only the ashes thrown out by the steamers which cross that part of the sea in great numbers. But a more careful examination shows well-marked débris of pumice and obsidian. Hence they must be considered as substances thrown up by volcanoes and probably by those not distant from these regions, those of Iceland, the Azores, the Antilles, or of Central America.

At the present time from numerous soundings, made in most varied regions, we learn that volcanic substances are spread generally over the great depths of the ocean. They oftenest form an incoherent, vitreous. and spongy material, similar to that designated for a long time by the name of *pumice*, from the name of the islands where it was found in ancient times. Their spongy texture is due to the gases and vapors which were disengaged from them before their substance was cold or hardened.

Often also, the substances brought by the dredges from the bottom of the sea are likewise of vitreous nature; but instead of being trachytic in composition like the pumice fragments, they are nearer to the basalts. The small fragments or *lapilli* are of the size of a nut or a pea.

It is remarkable that the vitreous texture, comparatively rare in the volcanoes of *terra firma*, should be so frequent in the volcanic débris which occupy the bottom of the sea, which seems to indicate that circumstances are favorable to its production in submarine eruptions.

Mr. Murray (in a communication made to the Royal Society of Edinburgh in 1876) was the first to bring to notice the importance and the large place that substances of volcanic origin occupy at great depths.

The original character however of the igneous ejections becomes more or less modified under the prolonged action of sea water. While the pumice changes to an earthy and friable matter, the pyroxenic *lapilli* produce a substance of brilliant luster similar to that named *palagonite* by Sartorius and Watterhausen. Some rock materials, such as the pumice fragments, from their porosity float for some time after reaching the surface of the sea before the water gradually penetrates their pores and carries them to the bottom. It is thus that the *Challenger* often found in its nets fragments of pumice, varying in bulk from the size of a man's head to that of a mustard seed, and usually round

in shape. This pumice resembled that from Lipari with elongated fibers and silky in appearance. Isolated bits floated on the surface of the sea, partly covered with the marine animals which had fastened themselves on its surface. The frequency of its appearance is easily explained, for the sea receives an enormous quantity of rock fragments of the same nature from many rivers flowing into it; such particularly is the case in New Zealand, in Japan, and in South America.

As is easy to understand, pulverulent material in suspension, coming from eruptions, has also been observed on the high seas.

Let us add that at various times navigators have remarked on the surface of the sea an accumulation of pumice under the form of a floating covering, sometimes so closely adhering and so extensive as to hinder the progress of ships. Such was the case in July, 1878, in the south of the Pacific Ocean, according to Capt. Turpey, and according to Capt. Harrington in March, 1879. The *Challenger*, however, did not observe in its passage any rafts of this sort.

The circumstances which accompanied the eruption of Krakatau or Rakata on the 27th of August, 1883,* are sufficient to account for the abundance of pumice at the bottom of the abyssal regions of the sea. At the time of this cataclysm the prodigious abundance of fine particles thrown out was such that the sky was obscured by them. An eye witness relates: "The sun being in mid-heaven, there was no light in the sky nor even a diffuse trace at the horizon, and this horrible night lasted eighteen hours. The ship *Loudon* was obliged to remain still where it was in view of the peril awaiting it." Some hours later, on the 28th of August, 500 kilometers west of the Straits of Sunda, the ship *le Salazie* met a violent storm, accompanied with lightning and fearful claps of thunder; after an interval of a few minutes the rain was replaced for thirty-six hours with sand which blinded the travellers, and soon after that by a white and impalpable dust, composed of pumice, so that at daybreak the ship appeared as though covered with snow.

The important share of fragmentary volcanic ejections in the depths of the sea thus receives an easy explanation as we shall see.

In regard to volcanoes situated upon continents, the extremely small particles known under the erroneous name of ashes and the little pebbles, grains, or *lapilli*, on account of their small size, are often carried by atmospheric currents to considerable distances and a great part of them reach the sea where they are finally deposited. The transportation of very fine particles has so to speak no limit, both in the air and in water which is in motion.

In addition to sub-aerial volcanoes, there are some whose opening or crater is submarine, so that the bottom of the sea is frequently the

* *Comptes Rendus of the Academy of Sciences*, 1883; vol. XCVI, p. 1100.

seat of the eruption. Recent soundings have revealed in the Great Ocean the presence of isolated and conical mountains, having the form characteristic of volcanoes and rising from the deep without however reaching the surface. Although circumstances do not favor their observation, submarine eruptions seem to be numerous. In many cases eruptions are betrayed by sulphurous emanations, columns of vapor, ejections of ashes, scoriæ, and pumice. Sometimes there appear islands formed of the incoherent débris which disappear later, as has been seen in the Mediterranean, as in the Atlantic—in the neighborhood of the Azores, and in the Pacific Ocean.

After the eruption of Krakatau an enormous deposit of this incoherent matter covered the whole country; its thickness over a radius of 15 kilometers was from 20 to 40 and sometimes 80 meters. Two islands, Stears-Eiland and Calmeyer-Eiland, formed by these ejections, were thrown up. There was formed also in a few hours an immense floating barrier of pumice, which closed the Bay of Kampong in the Straits of Sunda. The length of the barrier was nearly 30 kilometers by a width of more than 1 kilometer and a depth of 4 to 5 meters, or 150,000,000 of cubic meters of projectiles. It could then be seen how the wear and trituration of this friable material rubbing together is effected in the sea. Hitting and rubbing against each other, the stones became round and acquired the form of rolled pebbles, as generally shown in the pumice fished or dredged from the ocean. On the other hand, this trituration caused a multitude of very small splinters, similar in appearance and in mineralogical composition according to the examination made by Mr. Renard to the pulverized pumice brought up so abundantly by the dredges from the great depths. Mr. Verbeek estimates that the total volume of sand and cinders from this formidable cataclysm reached 18 cubic kilometers. Enormous as is this volume, it was exceeded by that thrown up by Timboro, or Tambora, in 1815, the volume of which was at least, it is said, 150 cubic kilometers.

The oceanic basins are favorably situated to receive from many points, and quite frequently, volcanic ejections; the general distribution of volcanoes on the surface of the globe explains the considerable part which their ejections occupy in the sea depths. In fact, the largest number of them, about seven-eighths, are situated in the long lineal series which wind about the Pacific Ocean as well as about many islands in that ocean. The circumference of this immense mass of water may be compared to a ring of fire where the volcanic action is scarcely ever interrupted. The Atlantic shows also numerous centers of activity of the same nature, both in the archipelagoes and in the continents which they border.

It must therefore happen that the small particles, ashes, and *lapilli*, which are projected from the eruptive openings of our planet, reach (for the most part), by reason of their fineness, to the great oceans; if they do not fall directly into them they are carried to them by the currents of air, and often to great distances from the crater whence they issued.

MINERAL SUBSTANCES OF EXTRA-TERRESTRIAL ORIGIN.

Among the substances which have been met in deep-sea deposits, there are some to which it does not seem to the authors possible to attribute a terrestrial origin. On account of their rarity they form only an insignificant portion of the deposits; but the interest they present results from the cosmic origin which we are led to attribute to them. In 1876 Mr. Murray called attention to the singular character of these particles.

In the midst of the portions which can be extracted by the magnet from certain muds of the abyss black microscopic globules are found, the interior of which consists of metallic iron, and they are covered with a pellicle of magnetic oxide. Traces of cobalt are found in them.

With these metallic spherules are associated others of the nature of stones; they are brown and of a bronze luster; their diameter averages a half a millimeter and never reaches twice that dimension. Microscopic examination proves that they are not strictly spherical, that their surface instead of being smooth is striated, and that their structure is laminated, taking an eccentric arrangement. These small bodies have then the texture as well as the form of those which abound in stony meteorites and which are characteristic of them. Like the latter, which Gustav Rose has designated under the name of *chondrules*, they consist of a silicate belonging to the species enstatite or bronzite. If we assume a meteorite to fall into the sea and become disintegrated, it will be easy for us to understand that such globules would be disengaged.

The metallic globules resemble wholly, in exterior appearance, those which are produced when bits of iron at white heat fly into the air, such for instance as are produced by the blow of the hammer on the anvil. Similar ones are doubtless produced when meteorites throw off sparks in traversing the atmosphere with great rapidity heated to incandescence. Messrs. Murray and Renard consider themselves, therefore, authorized to designate the metallic dusts, as well as the stony globules, as cosmic dusts.

It appears from a great number of examples that the cosmic dusts are found specially in the red clay which occupies the great depths of the Pacific, far from all continental land. Under these conditions the deposit seems to be of slight thickness and to be effected with extreme slowness. Facts which we witness daily render it easy to understand a cosmic co-operation in the building up of sub-marine deposts.

Every one has noticed the abundance of dust contained in the atmosphere that a ray of sun entering a dark room suffices to reveal. Such dust is still more apparent in the layer which settles upon all the objects in an uninhabited place, and even in the open country where the air is comparatively tranquil. It is more and more the unanimous opinion that the atmosphere is no less active a vehicle than water in the formation of sedimentary deposits.

Many observers have catalogued the substances contained in atmospheric dusts. We need not mention here the organic and organized particles, among which, as Mr. Pasteur and his pupils have shown us, microbes occupy such a preponderant place. What interests us is that the mineral grains are also prodigiously abundant. This mineral portion consists principally in very minute débris of terrestrial rocks, which, in spite of their extremely small dimensions, can be exactly determined by the microscope—such as quartz, limestone, the volcanic silicates, and oxide of iron, which are easily diagnosed.

In the course of these microscopic examinations, minute substances have been found differing entirely by their spherical form from the small fragments produced by the crushing of rocks. The substances in question resemble exactly the hollow globules or vesicles of oxide which the quick combustion of metallic iron gives for example, when the old-fashioned tinder box is used or when a horse's shoe strikes sparks from the pavement. It is legitimate, however, not to consider all these globules as having an artificial origin.

Two classes of considerations may be appealed to on this subject.

First, it is demonstrated that lumps formed of metallic iron or containing granules of that metal, reach us from celestial space and undergo in the higher regions of the atmosphere an artificial combustion. The latter fact is manifested by the long trains of smoke, often persistent, which accompany the meteorites. They contain very probably globules analogous to those produced from horse-shoes on the pavement.

In several circumstances the enormous volume of the dust in question has been ascertained from the clouds or trails which have accompanied the fall of celestial bodies. By reason of the importance of the fact, we will cite several examples.

At the time of the fall of the holosiderite, or iron of Hraschina, near Agram (May 26, 1751), there was perceived, after the explosion, a black cloud which lasted, it is said, for three hours and a half after the fall.

At the moment of the fall of the iron of Braunau, in Hungary, which took place July 14, 1847, many persons, warned by two violent reports, remarked a small black cloud which appeared horizontally, with the accompaniment of violent reports; two globes of fire, which issued from the cloud, fell upon the ground. The cloud became gray and then disappeared.

The mass from which, on the 14th of May, 1863, chondritic meteorites fell in the environs of Orgueil (Tarn et Garonne), gave forth a jet of sparks; then left behind it a trail, which was at first luminous, and then changed to a cloud, lasting from eight to ten minutes.

Before the explosion of the meteorite to which we owe the aërolites which fell on the 9th of December, 1858, at Ausson and at Clarac, near Montrejeau (Haute Garonne), a considerable jet of incandescent smoke was seen to escape from the nucleus. A cloud of whitish

vapor formed in the center of the explosion, and a trail of the same vapor lasted with this cloud over the whole line followed by the meteor.

The fall at Aigle, May 26, 1803, according to the circumstantial narrative of Biot, was announced by a flaming globe accompanied by a violent explosion which lasted five or six minutes; it was at first like four cannon shots, then a discharge resembling a volley of musketry. This noise came from a small, very high cloud of a rectangular shape which seemed motionless all the time the phenomena lasted.

Beside the fall of meteorites, properly so-called, it is certain that cosmic dusts also fall. They have not attracted as much attention as they should, for it is difficult to distinguish them from those of terrestrial origin, which are incomparably the most numerous. They are recognized however, when preceded by the remarkable phenomena of light and noise which we have just mentioned. The catalogue published by Chladni in 1824 informs us of several examples, among which is the following: In 1819, in Montreal, Canada, a black rain was observed, accompanied by an extraordinary darkening of the sky, and reports like those from artillery, and very brilliant lights. At first it was supposed to be a fire in a neighboring forest, coinciding with a violent storm. But the whole phenomenon and the examination of the matter which fell proved that it was due to the arrival in the atmosphere of substances foreign to our globe.

There fell at Lœbau, in Saxony, January 13, 1835, a powder formed of magnetic oxide. This fall followed the explosion of a bolide which moved, it was said, with extraordinary swiftness, and the flashes from which seemed to burn in passing through the atmosphere.

The chondritic meteorites of Orgueil, the appearance of which in the atmosphere has been mentioned, and which are so interesting from many points of view, were very instructive with regard to the existence of meteoric dust. They are friable to such a degree that several specimens were reduced to powder by simple pressure between the fingers. It is a matter of astonishment that they reached the surface of the globe whole. Perhaps this fact may be explained by presenting the two following circumstances: At first each fragment was enveloped at the moment of fall with a vitrified crust more solid than the rest of the mass. Also, the various portions of the substance are cemented by alkaline salts. Water in dissolving this cement brings about the complete disintegration of the meteorite, which turns to powder of the most extreme tenuity. So that if on the 14th of May, 1864, the sky, instead of being perfectly clear had been rainy, or merely covered with clouds through which the stones would have had to pass, nothing could have been gathered up but a viscous mud, the fall of which has been observed on several occasions.

In addition to the facts derived from contemporary phenomena, a second argument for belief in the cosmic origin of certain ferruginous

globules collected in atmospheric dust arises from the discovery that has been made of quite similar globules in sediments anterior to the existence of man, several of which date even from very remote geological periods. To limit our examples, we will mention, according to Messrs. G. Tissandier and Stanilas Meunier,* the abundance of the small bodies in question in the green sand and the clays under the sheet of bubbling water of the artesian wells of Paris.

This cosmic origin makes it clear how similar dust would abound in regions far removed from any inhabited place. At the summit of the highest mountains, upon Mont Blanc, for example, the melted snow water gives a sediment in which the globules we speak of are not wanting.

The presence of nickel in certain dust seems to confirm their extraterrestrial origin. Such was the case with those which Mr. Albert Tissandier collected on the *col des Tours* at 2,710 meters of altitude, on the occasion of his ascension in 1877.

From the limited number of falling meteorites, the products of which are collected each year, a very incomplete idea is formed of their frequency. The enormous majority necessarily escapes the most eager search even in the midst of the densest populations, either being disguised in the vegetation, on account of their usual smallness of size, or else because they enter the soil. The largest number also fall in uninhabited or savage countries and specially in the basin of the seas.

It is thus recognized *a priori* that cosmic dusts must exist not only on the surface of continents, but also on the basin of oceans.

Without diminishing the incontestable importance of the facts just set forth, there must also be taken into account certain geological phenomena to which the mineral globules may owe their birth. Such is the opening of vertical canals like volcanic chimneys, which under the names of *diatremes* traverse the terrestrial crust, the production of which I have recently realized by the experimental method.†

The perforation of different rocks, traversed by currents of gas which has at the same time a very strong pressure, a great swiftness, and a high temperature must have produced dusts, the spheroidal grains of which, often hollow, are very abundant.

CHEMICAL AND MINERALOGICAL PRODUCTIONS FORMED ON THE GREAT OCEAN BOTTOMS.

We see every day on the continents rocks of very different kinds chemically modified under the mere action of air and water, and thus giving birth to new substances. In the same way the deposits formed in the depths of the sea have not escaped certain chemical actions, in spite of the temperature near zero which reigns there. A state of

* *Comptes Rendus of the Academy of Sciences*; 1878; vol. LXXXVI, p. 450.

† Experiments upon the possible effects of subterranean gases. *Comptes Rendus of the Academy of Sciences*, 1891; vols. CXI and CXII.

extreme fineness renders them all the more susceptible of influence. The mineral substances which sea water holds in solution contribute no doubt actively in these modifications.

Before the expedition of the *Challenger* the results of these reactions and the mineral species produced therefrom were, for the most part, unknown, although such species occupy a large portion of the ocean bed. The exact study which has been made of them by the *Challenger* constitutes for geologists and mineralogists perhaps the most interesting part of the exploration. We will review in succession the species which have been ascertained.

Red clay.—Of all marine sediments the type most widely spread over the deep seas has received the name of *red clay*. It is essentially a hydrated silicate of alumina, the color of which is due to an intimate mixture of peroxide of iron; sometimes also it takes a brown color from the oxide of manganese. Plastic, like most of the clays, greasy to the touch, it can be molded in the fingers. When dry it adheres in a coherent mass, and subjected to the blow-pipe, it is fused into a black, magnetic globule.

In spite of its homogeneous appearance it is rare that red clay is not mixed with very small fragments of pumice and other volcanic productions. When they are not recognizable by the naked eye this débris reveals its granular nature to the touch. Accidentally red clay may also contain detritus of continental origin, drifted by floating ice or carried far by winds. All this débris is very fine, and it rarely exceeds one-twentieth of a millimeter.

Usually red clay is associated with calcareous and siliceous débris, coming from organisms of a microscopic size, which have been mentioned above. These organisms are mixed in variable proportions, and sometimes predominate so as to greatly modify their aspect. Hence the names *globigerina ooze* and *radiolarian ooze*, according as one or the other of those beings characterize it. Each of these categories of deposits in the great bottoms occupies vast extents. (The area of the radiolarian ooze extends specially between latitudes 20 degrees north and 10 degrees south; the globigerina oozes occupy nearly 110 degrees of latitude, and attain sometimes 5,000 meters in depth. Both disappear near the polar regions.) The terrigenous deposits represent only 14 per cent of the superficies of sea bottoms, the red clay occupies 38 per cent, and the globigerina mud 36 per cent. The diatomacea, a sort of algæ with a siliceous skeleton, specially abound toward the polar regions. Thus, as we have said, these various organisms have lived for the most part in the waters of the surface, whence their solid débris have fallen after death into the depths. Vast regions of the Pacific, of the Atlantic, and of the Indian Ocean are occupied with red clay, associated with microscopic organisms. According to a numerous series of soundings, as the depth is greater, the calcareous shell of various organisms disappears gradually from the slimy sediment, so

that finally, far from the surface nothing is found but the red clay, entirely without lime, under organized form. The shells of pteropods disappear first, then the envelopes of the foraminifers, which a coating of organic matter seemed to protect. It seems probable that this elimination of carbonate of lime is due to the action of carbonic acid dissolved in the deep layers of oceanic waters, where its chemical activity is reinforced by the enormous pressure that reigns. The silica of the organisms resists the best, and it is thus that their skeletons, spicules, and other siliceous vestiges accumulate on the bottom.

Everything seems to indicate that the formation of red clay is essentially due, like that of most of the other minerals which are to come under our notice, to the decomposition of the incoherent and very tenuous volcanic productions which abound on all the great ocean beds. In the regions where red clay shows its most distinct characteristics this transformation of the volcanic rocks into clayey matter may be followed through its successive phases. The clayey matter is the direct product of a chemical decomposition, specially of the silicates, which are basic and in part represented by the pumice and the volcanic glasses.

Ebelmen,* so prematurely taken away from science, which he endowed with discoveries full of genius, was the first to show how the aluminous silicate rocks, principally those of eruptive origin, so frequent at the surface of the globe, are decomposed by the mere action of the atmosphere; their protoxides, such as lime and magnesia, are carried off in a state of carbonate, while the alumina is concentrated with the silica, so as to form a hydrated silicate of the clay family.

The same slow reactions seem to take place upon the ocean bottom at the expense of the volcanic silicates, aided perhaps by the chemical action of the sea water. Certain fusible muds contain, very probably, portions still undecomposed, but in such fine dust that they may be confounded with the clay. It has been so with the muds that I have obtained by experiments upon the trituration of feldspar; they are so finely divided that they are soft as clay to the touch and possess the same plasticity.

Zeolites.—Notwithstanding the very low temperature which prevails at the ocean bed, the chemical reactions seem to produce sharply-crystalized minerals, the most remarkable of which, without doubt, belongs to the double hydrated silicates, known under the name of zeolites. These zeolites are met with in great abundance under the form of small isolated crystals, simple or grouped geometrically, often in spherules of hardly a half millimeter in diameter, and in all cases confused with the clay. Crystallographic and chemical analyses show that they must belong to the species called *christianite* or *philippsite*. This discovery was made in the center of the Pacific. It was repeated

*See the article by Mr. Chevreul in the *Journal des Savants*, 1884, p. 104.

in the Indian Ocean. It might have been thought that these innumerable crystals of christianite came from the simple disintegration of volcanic rocks, with the paste of which they would have been associated; but the foraminifers brought up from the deeps by the dredge are completely enveloped with crystalline coverings of this mineral, which proves the fact not to be so. The formation of the zeolite is posterior to the deposit of the sediments engendered by the transformation of volcanic substances which cover the bed of the sea.

Glauconite.—Among the mineral deposits found on the sea bottoms is another hydrated silicate, known under the name of *glauconite*, which has for its bases aluminium, protoxide of iron, and other metals. Its mode of formation as well as the great extents on which it is found, specially call attention to it. It takes the form of small grains of a green color, and completely similar in form, dimension, and appearance, to the particles of the same mineral which abound in various geological periods of the series of stratified rocks from the most ancient times to the most recent. Glauconite thus plays an important part in space as well as in time. The formation of this mineral in the great sea deeps, brought to notice forty years ago by Bailey and Pourtalès, has been the object of many investigations, specially by Ehrenberg.

Hydrated oxide of manganese (*wad*); *hydrated oxide of iron* (*limonite*).—Two other species to be mentioned, which submarine chemistry has produced, and no doubt is still producing, are the hydrated oxides of manganese and of iron, which are specially observed in nodules. These substances are disseminated over the whole surface of the sea-bottom, but specially in the red clay area. It is easy to understand this association; the volcanic rocks from which these clays are obtained containing abundance of iron and manganese in their mineral constituents, peridot, pyroxen, and others. In consequence of their decomposition the oxides are liberated in conformity with the reactions so ably demonstrated by Ebelmen.*

Among the organic and inorganic débris which in the red clay regions serve as center to the ferro-manganiferous concretions, the remains of vertebrates have been frequently found. The bones thus found are the most enduring portions of the skeleton, such as the tympanic bones of the cetacea and the teeth of the shark. Just as we see the calcareous organisms eliminated at great depths, so also it is found that, except these massive portions, all bones of vertebrates are missing in the deep sediments. Some of these remains of vertebrates belong to extinct species.

Phosphate of lime.—Off the cape of Good Hope, the dredge brought up from various depths of between 200 and 4,000 meters, quartzy and glauconitic muds, charged with the remains of various organisms, some

* In an appendix Mr. Gibson points out, by the aid of spectroscopic analysis, in the manganese nodules, traces of various elements, barium, strontium, lithium, titanium, vanadium, and thallium.

of a calcareous nature, like the foraminifers, others of a siliceous nature, like the spiculæ of sponges, the radiolaria, and the diatomacea.

In these muds are found solid concretions from 1 to 4 centimeters in diameter and embedding all the organic and inorganic elements of the sediment. Chemical analysis has demonstrated that the cement of these concretions consists principally of phosphate of lime.

The sediments with the phosphatic nodules present the greatest resemblance to certain well-known strata belonging to various stages of certain series, especially of the cretaceous period, viz, the green sandstone, the glauconitic sandstone, the white chalk. The resemblance, which is not only in the nodules, but also in the sediments which contain them, is such that there is evident similarity in their mode of formation.

In regard to the origin of this phosphate of lime, the simplest idea and the one that everything confirms is that it is derived immediately from the decomposition of animal débris buried in the sediment after death. Their form is destroyed by the effect of the reactions of the sea water upon them.

GENERAL OBSERVATIONS.

The expedition of the *Challenger* deserves the gratitude of science, not alone because it has shed light upon important facts in the province of physical geography, and because it has furnished many new ideas of the animal and vegetable life that people the abysses of the ocean. The nature of the bed of those abysses, vast areas whose depth exceeds 4,000 meters and sometimes attain more than 8,000 meters, was, but a short time ago, hardly known to us. Deposits formed from the terra firma observable not far from continents do not continue in the abysmal regions, where the motions of the sea, to which marginal deposits owe their origin, exert no influence.

In those regions, mineral particles upon which the mechanical action of the water has left an imprint are not to be found, but instead volcanic and pulverized matter, as well as clayey substances produced by their chemical decomposition, the whole mixed with remains of microscopic organisms. Such are the deposits which cover the largest part of the sub-marine crust of the globe.

We see for the first time the principal outlines of a geological map of the sea bottom, showing the manner in which the different types of deposits are distributed upon the great ocean beds. This map is annexed to the volume; it contains, in synoptic form and in conventionalized colors, the results of more than two thousand soundings made at depths greater than 2,000 meters.*

Among other facts which appear from the map in question, the first to attract the attention is how much the abyssal deposits exceed the

* There were 1,600 of these soundings in the Atlantic, 300 in the Indian Ocean, and 400 in the Pacific.

marginal deposits in extent. The great predominance of red clay and globigerina-mud ooze is noticed at first sight both in the Atlantic and in the Pacific. In regard to the diatom ooze, it is seen to abound in the Antarctic Ocean beyond 50 degrees of latitude.

The deposits in the abyssal regions are in complete contrast not only with the present deposits of seas less deep, but also in a marked way with those formed in the seas in ancient geological periods and which, laid down for a depth of thousands of meters, constitute the series of stratified rocks.

In these ancient formations the sediments of abyssal nature seem to be lacking, or to be at least very rare. Hence the conclusion that the parts of the sea where sedimentary earths are successively formed are not, as to conditions of depth, comparable to those where the abyssal regions of the Atlantic and Pacific are found. They were not very far from the emerged portions or continents, and did not attain to very great depths.

We are therefore led to the conclusion that from the most remote epochs the continental elevations have occupied very nearly the same parts of the globe. The prominences have been gradually modified by general upheavals, as has happened on a small scale, for example, in the formation of the Alpine chain. The great depressions then go back to a great antiquity and the general configuration of the terrestrial spheroid, with its vast and deep depressions as we now know them, must have been outlined from the most ancient epochs of its history.

This is the confirmation of an idea which has been previously reached from other considerations Agassiz formulated it in 1872, in discussing the observations made by Pourtalès upon the deeps of the Atlantic, and in remarking that no vestiges of stratified earth, either ancient or modern, were to be found there.

Various facts lead us to think that the clay which covers the bottom of the oceanic basins was deposited with extreme slowness. The deposit seems not to have been thick and seems to go back, at least in certain parts, to very remote periods. This explains the relative abundance with which the cosmic dusts, as well as the more enduring of the cetaceous remains, are found there. The terrigenous deposits accumulate upon an entirely different scale of rapidity.

Now that we know the mode of formation of the deposits in the great deeps of the sea, and the chemical reactions producing the various species of minerals, new horizons are opened to us with regard to phenomena of which we formerly had no idea, and which nevertheless has for its stage more than half the solid crust of our planet.

The examination of the beautiful work under our notice shows how numerous are the facts upon which the conclusions of the authors are based. It proves also the conscientious care which was bestowed upon the specimens procured which were examined by all the methods known to science.

Let us do honor then to the men who organized the expedition of the *Challenger*, to those men who carried it out with so much courage, energy, and skill, and let us render no less worthy homage to the two scientists Mr. John Murray and Mr. A. F. Renard, the important results of whose labors we have endeavored to set forth.

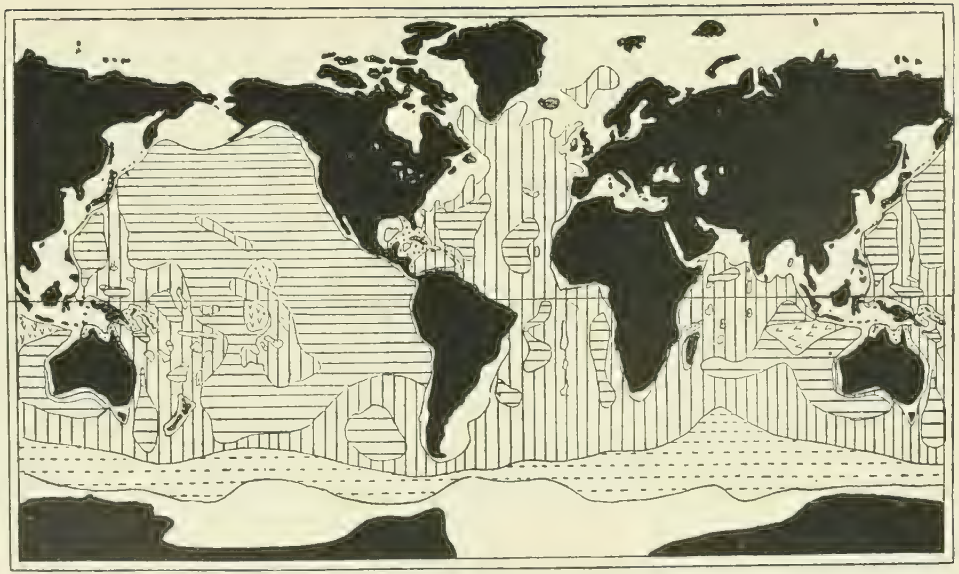

CHART I. OCEAN DEPOSITS. White space bordering lands, Terrigenous deposits; vertical lines, Globigerina ooze; horizontal lines, Red clay; broken horizontal lines, Diatom ooze; two areas marked V are Radiolarian ooze; dotted spaces, Coral sands and muds; a few white spaces, Pteropod ooze.

(Reproduced from "Knowledge," March 1, 1893.)

CHART II. OCEAN CONTOURS. White space bordering lands, shallow waters up to 1,000 fathoms; vertical lines, 1,000 to 2,000 fathoms; horizontal lines. 2,000 to 3,000 fathoms; squares, 3,000 to 4,000 fathoms; fine cross, over 4,000 fathoms.

(Reproduced from "Knowledge," March 1, 1893.)

THE MIGRATIONS OF THE RACES OF MEN CONSIDERED HISTORICALLY.*

By Prof. JAMES BRYCE.

There are two senses in which we may claim for geography that it is a meeting point of the sciences. All the departments of research which deal with external nature touch one another in and through it—geology, botany, zoology, meteorology, as well as, though less directly, the various branches of physics. There is no one of these whose data are not, to a greater or less extent, also within the province of geography; none whose conclusions have not a material bearing on geographical problems; and geography is also the point of contact between the sciences of Nature, taken all together, and the branches of inquiry which deal with man and his institutions. Geography gathers up the results which the geologist, the botanist, the zoologist, and the meteorologist have obtained, and presents them to the student of history, of economics, of politics—we might, perhaps, add of law, of philology, and of architecture—as an important part of the data from which he must start, and of the materials to which he will have to refer at many points in the progress of his researches. It is with this second point of contact, this aspect of geography as the basis for history, that we are to occupy ourselves to-night. Understanding that the Scottish Geographical Society desires not merely to present a current history of discovery, but to bring into prominence the economic, social, and political aspects of the science, and to inculcate its significance for those who devote themselves to the presently urgent problems which civilized man is called to deal with, I have chosen, as not unsuitable to an inaugural address, a subject which belongs almost equally to physical and descriptive geography on the one side, to history and economics on the other. The movements of the races and tribes of mankind over the surface of our planet are in the first instance determined mainly by the physical conditions of its surface and its atmosphere, but they become themselves a part, and, indeed, a great part, of history: they create nations and build up states; they determine the extension of languages and laws;

* Read at the inaugural meeting of the London branch of the Royal Scottish Geographical Society, April, 1892. (*The Scottish Geographical Magazine*, August, 1892; vol. VIII, pp. 400–421.)

they bring wealth to some regions and leave others neglected; they mark out the routes of commerce and affect the economic relations of different countries.

No line of historical inquiry sets before us more clearly at every stage the connection between man as an associative being—toiling, trading, warring, ruling, legislating—and that physical environment whose influence over his development is none the less potent and constant because he has learned in obeying it to rule it and to make it yield to him constantly increasing benefits. The topic is so large and branches off into so many other cognate inquiries that you will not expect me, within the narrow limits of an address, to do more than draw its outlines, enumerate the principal causes whose action it sets before us, touch upon the successive epochs which its history presents, and refer to a few out of the many problems its consideration raises. The migrations of peoples have been among the most potent factors in making the world of to-day different from the world of thirty centuries ago. If they continue they will be scarcely less potent in their influence on the future of the race; if they pass into new phases, those phases will be the expression of new conditions of society; if they cease, that cessation will itself be a fact of the highest economic and social significance.

I.—FORMS OF DIFFUSION.

At the outset it is convenient to distinguish the different forms which movements of population have taken. These forms may be grouped under three heads, which I propose to call by the names of Transference, Dispersion, and Permeation—names which need a few words of illustration.

1. By Transference I mean that form of migration in which the whole, or a large majority, of a race or tribe quits its ancient seats in a body and moves into some other region. Such migrations seldom occur except in the case of nomad peoples who are little attached to any particular piece of soil; but we may almost class among the nomads tribes who, like our own remote Teutonic ancestors, although they cultivate the soil, put no capital into it in the way of permanent improvements, and build no dwellings of brick or stone. The prehistoric migrations usually belonged to this form, and so did that great series of movements which brought the northern races into the Roman Empire in the fifth and sixth centuries of our era. In modern times we find few instances of Transference, because such nomad races as remain are now shut up within narrow limits by the settled States that surround them, which have possessed, since the invention of gunpowder and of standing armies, enormously superior defensive strength.* We should however have had an interesting case to point to had the Dutch, when pressed by the power of Philip II, embraced the offer that came to them from

* In 1771 a great Kalmuk horde moved en masse from the steppes of the Caspian to the frontiers of China, losing more than half its numbers on the way.

England to migrate in a body and establish themselves, their dairying, their flax culture, and their linen manufacture, in the rich pastures and humid air of Ireland.

2. Under the head of migrations by Dispersion I include those cases in which a tribe or race, while retaining its ancient seats, overflows into new lands, whether vacant or already occupied; in the latter event sometimes ejecting the original inhabitants, sometimes fusing with them, sometimes dwelling among them, but remaining distinct.

Examples are furnished by the case of the Norsemen, who found Iceland practically vacant, while in England they became easily, in Ireland and Gaul more slowly, mingled with the previous inhabitants. When our own ancestors came from the Frisian coast they slew or drove out the bulk of the Celtic population of Eastern Britain; when the Franks entered Gaul they became commingled with it. It is by such a process of dispersion that the British race has spread itself out over North America and Australasia. In much smaller numbers the Spaniards diffused themselves over southern North America, and the northern and western parts of South America; and by a similar process the Russians have for two centuries been very slowly filling the better parts of Siberia. Whether in any case of dispersion the migrating population becomes fused with that which it finds, depends chiefly on the difference between the level of civilization of the two races. Between the English settlers in North America and the native Indians there has been hardly any mixture of blood; between the French in Canada and the Indians there was a little more; between the Spaniards and the less barbarous inhabitants of Mexico there has been so much that the present Mexican nation is a mixed one, the native blood doubtless predominating. Something however also depends on the relative numbers of the two races; and sometimes religion keeps a dispersed people from commingling with those among whom it dwells, as has happened in the case of the Jews, the Armenians, and the Parsees. These last are a remarkable instance of an extremely small nation—for there are not 80,000 of them all told—who, without any political organization, have, by virtue of their religion, preserved their identity for more than a thousand years. Dispersion has been the most widely operative form of migration in modern times which have enabled remote parts of our large world, separated by broad and stormy seas, to be colonized more easily than in the tiny world of ancient or mediæval times was possible either by land or by sea.

3. The third form, which we may call Permeation or Assimilation, is not in strictness a form of migration at all, because it may exist where the number of persons changing their dwelling-place is extremely small; but it deserves to be reckoned with the other two forms because it produces effects closely resembling theirs in altering the character of a population. I use the term Permeation to cover those instances, both numerous and important, in which one race or nation

so spreads over another race or nation its language, its literature, its religion, its institutions, its customs, or some one or more of these sources of influence, as to impart its own character to the nation so influenced, and thus to substitute its own for the original type. In such a process the infusion of new blood from the stronger people to the weaker may be comparatively slight, yet, if sufficient time be allowed, the process may end by a virtual identification of the two. Of course, when there is much intermarriage, not only does the change proceed faster, but it tells on the permeating as well as on the permeated race. The earliest recorded instance of this diffusion of a civilization with little immixture of blood is to be found in the action of the Greek language, ideas, and manners upon the countries round the eastern half of the Mediterranean, and particularly upon Asia Minor. The native languages, to some extent, held their ground for a while in the wilder parts of the interior, but the upper classes and the whole type of culture became everywhere Hellenic. In the same way the Romans Romanized Gaul and Spain and the more fertile regions of North Africa. In the same way the Arabs, in the centuries immediately after Mohammed, Arabized not only Egypt and Syria, but the whole of North Africa down to and including the maritime parts of Morocco, and have in later times, though to a far smaller extent, established the influence of their language and religion on the coasts of East Africa and in parts of the East Indian Archipelago. There is reason to believe, though our data are scanty, that in somewhat similar way the Aryan tribes, who entered India at a very remote time, diffused their language, religion, and customs over northern Hindustan as far as the Bay of Bengal, changing to some extent the dark races whom they found in possession of the country, but being also so commingled with those more numerous races as to lose much of their own character. Hinduism and languages derived from Sanskrit came to prevail from the Indus to the Brahmaputra, although it would seem that to the east of the Jumna the proportion of Aryan intruders was very small. We ourselves in India are giving to the educated and wealthier class so much that is English in the way of ideas and literature, that if the process continues for another century, our tongue may have become the *lingua franca* of India, and our type of civilization have extinguished all others. Yet if this happens it will happen with no mixture of blood between the European and the native races, possibly with little social intimacy between them. The instances just mentioned show in what different ways and varying degrees assimilation may take place. In some of them the assimilated race still retains a distinct national character. The Moor of Morocco, for instance, differs from the Arab much as the Greek-speaking Syrian and the Latin-speaking Lusitanian differed from a Greek of Attica or a Roman of Latium. But the Finnish tribes of northern and eastern Russia, Voguls, Tcheremisses, Tchuvasses, and Mordvins, who have been gradually Russified

during the last two centuries, are on their way to become practically undistinguishable from the true Slavonic Russians of Kieff. And, to come nearer home, the Celts of Cornwall have been anglicized, and those of the Highlands of Scotland have in many districts become assimilated to the Lowland Scotch, with no great intermixture of blood.

It is worth while to be exact in distinguishing this process of Permeation from cases of Dispersion, because the two often go together—that is to say, the migration of a certain, though perhaps a small, number of persons of a vigorous and masterful race into a territory inhabited by another race of less force, or perhaps on a lower level of culture, is apt to be followed by a predominance of the stronger type, or at any rate by such a change in the character of the whole population as leads men in later times to assume that the number of migrating persons must have been large. The cases of the Greeks in Western Asia and the Spaniards in the New World are in point. We talk of Asia Minor as if it had become a Greek country under Alexander's successors, of Mexico and Peru as Spanish countries after the sixteenth century, yet in both instances the native population must have largely preponderated. If therefore, we were to look only at the changes which the speech, the customs, the ideas, and institutions of nations have undergone, we might be disposed to attribute too much to the mere movement of races, too little to the influences which force of character, fertility of intellect, and command of scientific resource have exercised, and are still exercising, as the leading races become more and more the owners and rulers of the backward regions of the world.

II.—CAUSES OF MIGRATION.

We may now proceed to inquire what have been the main causes to which an outflow or an overflow of population from one region to another is due. Omitting, for the present, the cases of small colonies founded for special purposes, these causes may be reduced to three. They are food, war, and labor. These three correspond in a sort of a rough way to three stages in the progress of mankind, the first belonging especially to his savage and semi civilized conditions, the second to that in which he organizes himself in political communities, and uses his organization to prey upon or reduce to servitude his weaker neighbors; the third to that wherein industry and commerce have become the ruling factors in his society and wealth the main object of his efforts. The correspondence however is far from exact, because the need of subsistence remains through the combative and industrial periods a potent cause of migration, while the love of war and plunder, active even among savages, is by no means extinct in the mature civilization of to-day.

1. In speaking of food, or rather the want of food, as a cause, we must include several sets of cases. One is that in which sheer hunger, due perhaps to a drought or a hard winter, drives a tribe to move to some

new region where the beasts of chase are more numerous, or the pastures are not exhausted, or a more copious rain-fall favors agriculture.* Another is that of a tribe increasing so fast that the pre-existing means of subsistence no longer suffice for its wants. And a third is that where, whether or not famine be present to spur its action, a people conceives the desire for life in a richer soil or a more genial climate. To one or other of these cases we may refer nearly all the movements of populations in primitive times, the best known of which are those which brought the Teutonic and Slavonic tribes into the Roman Empire. They had a hard life in northern and eastern Europe; their natural growth exceeded the resources which their pastoral or village area supplied, and when once one or two had begun to press upon their neighbors, the disturbance was felt by each in succession until some, pushed up against the very gates of the Empire, found those gates undefended, entered the tempting countries that lay towards the Mediterranean and the ocean, and drew others on to follow. Of modern instances the most remarkable is the stream of emigration which began to swell out of Ireland after the great famine of 1846–'47, and which has not yet ceased to flow.

Among civilized peoples the same force is felt in a slightly different form. As population increases the competition for the means of livelihood becomes more intense, while at the same time the standard of comfort tends to rise. Hence, those on whom the pressure falls heaviest (if they are not too shiftless to move), and those who have the keenest wish to better their condition, forsake their homes for lands that lie under another sun. It is thus that the Russian peasantry have been steadily moving from the north to the south of European Russia, till they have now occupied the soil down to the very foot of the Caucasus for some 500 miles from the point they had reached a century and a half ago. It is thus that, on a smaller scale, the Greek-speaking population of the west coast of Asia Minor is creeping eastward up the river valleys, and beginning to re-colonize the interior of that once prosperous region. It is thus that North America and Australasia have been filled by the overflow of Europe during the last sixty years, for before that time the growth of the United States and of Canada had been mainly a home growth from the small seeds planted two hundred years earlier. That the mere spirit of enterprise, apart from the increase of population, counts for little as a cause of migration, seems to be shown not only by the slight outflow from Europe during last century, but by the fact that France, where the population is practically stationary, sends out no emigrants save a few to Algeria, while the steady movement from Norway and Sweden does little more than relieve the natural growth of the population of those countries. As regards European

* A succession of dry seasons, which may merely diminish the harvests of those who inhabit tolerably humid regions, will produce such a famine in the inner parts of a continent like Asia as to force the people to seek some better dwelling-place.

emigration to America, it is worth noting that during the last thirty years it has been steadily extending, not only eastward toward the inland parts of Europe, but also downward in the scale of civilization, tapping, so to speak, lower and lower strata. Between 1840 and 1850 the flow toward America was chiefly from the British Isles. From 1849 onward, it began to be considerable from Germany also, and very shortly afterward from Scandinavia, reaching a figure of hundreds of thousands from the European continent in each year. From Germany the migratory tendency spread into Bohemia, Moravia, Poland, and the other Slavonic regions of the Austro-Hungarian monarchy, as well as into Italy. To-day the people of the United States, who had welcomed industrious Germans and hardy Scandinavians because both made good citizens, become daily more restive under the ignorant and semi-civilized masses whom Central Europe flings upon their shores. At the other end of the world, the vast emigration from China is partly attributable to the need of food; but to this I shall recur presently when we come to speak of labor.

2. The second of our causes is war. In early times, or among the rude peoples, it is rather to be called plunder, for most of their wars were undertaken less for permanent conquest than for booty. The invasions of Britain by the English, of Gaul by the Franks, of England and Scotland by the Norsemen and Danes, all began with mere piratical or raiding expeditions, though ending in considerable transfers of population. The same may be said of the conquest of Pegu and Arakan by the Burmese in the last century, and (to a smaller extent) of that southward movement of the wild Chin and Kachin tribes whom our present rulers of Burmah find so troublesome. It was in war raids that the movement of the Bantu races to the southernmost parts of South Africa, where they have so largely displaced the yellowish Hottentot race, seems to have begun. So the conquests of Egypt and Persia by the first successors of the Prophet, so the conquests of Mexico and Peru by the Spaniards, though tinged with religious propagandism, were primarily expeditions in search of plunder. This character, indeed, belongs all through to the Spanish migrations to the New World. Apparently few people went from Spain meaning, like our colonists a century later, to make a living by their own labor from the soil or from commerce, which, indeed, the climate of Central and South America would have rendered a more difficult task. They went to enrich themselves by robbing the natives or by getting the precious metals from the toil of natives in the mines, a form of commercial enterprise whose methods made it scarcely distinguishable from rapine. In modern times the discovery of the precious metals has helped to swell the stream of immigration, as when gold was discovered in California in 1846 and in Australia a little later; but in these instances, though enrichment is the object, rapine is no longer the means. There are, however, other senses in which we may call war a source of movements of races. It was military policy which planted the Saxons in Transylvania and the French in Lower Canada, and the

Scotch and English settlers in the lower and more fertile parts of Ulster; it is military policy which has settled Russian colonies, sometimes armed, sometimes of agricultural dissenters, along the Trans-caucasian frontiers and on the farther shore of the Caspian. It was military policy which led Shalmaneser and Nebuchadnezzar to carry off large parts of the people of Israel and Judah to settle them in the cities of the Medes or by the waters of Babylon.*

As regards the more regular conquests made by civilized states in modern times, such as those of Finland, Poland, Transcaucasia, and Transcaspia by Russia, of Bosnia and Herzegovina by Austria, of India and Cape Colony by Great Britain, of Cochin China and Annam by France, it may be said that they seldom result in any considerable transfer of population. Such effects as they have are rather due to that process of Permeation which we have already considered.

3. Labor (*i. e.*, the need for labor) becomes a potent cause of migrations in this way—that the necessity for having in particular parts of the world men who can undertake a given kind of toil under given climatic conditions draws such men to those countries from their previous dwelling place. This set of cases differs from the cases of migrations in search of subsistence, because the migrating population may have been tolerably well off at home. As the food migrations have been described as an outflow from countries overstocked with inhabitants, so in these cases of labor migration what we remark is the inflow of masses of men to fill a vacuum—that is, to supply the absence in the country to which they move of the sort of workpeople it requires. However, it often happens that the two phenomena coincide, the vacuum in one country helping to determine the direction of the influx from those other countries whose population is already superabundant. This has happened in the case of the most remarkable of such recent overflows, that of the Chinese over the coasts and islands of the Pacific. The need of Western America for cheap labor to make railways and to cultivate large areas just brought under tillage, as well as to supply domestic service, drew the Chinese to California and Oregon, and but for the stringent prohibitions of recent legislation would have brought many thousands of them into the Mississippi Valley. Similar conditions were drawing them in great numbers to Australia, and especially to North Queensland, whose climate is too hot for whites to work in the fields; but here, also, the influx has been stopped by law. Ten or twelve years ago they were beginning to form so considerable a proportion of the population of the Hawaiian Isles that public opinion there compelled the sugar-planters to cease importing them, and, in order to balance them, Portuguese labor was brought from the Azores, and Japanese from Japan. Into Siam and the Malay Peninsula, and over the Eastern Archipelago, Chinese migra-

* So the Siamese, after their conquest of Tenasserim, carried off many of the Talain population and settled them near Bangkok, where they remain as a distinct population to this day.

tion goes on steadily; and it seems not improbable that in time this element may be the prevailing one in the whole of the Indo-China and the adjoining islands, for the Chinese are not only a more prolific but altogether a stronger and hardier stock than either their relatives the Shans, Burmese, and Annamese, or their less immediate neighbors the Malays. If in the distant future there comes to be a time in which the weaker races having been trodden down or absorbed by the more vigorous, few are left to strive for the mastery of the world, the Chinese will be one of those few. None has a greater tenacity of life.

Not unlike these Chinese migrations, but on a smaller scale, is that of Santhals to Assam, and of South Indian coolies to Ceylon (where the native population was comparatively indolent), and latterly to the isles and coasts of the Carribbean Sea. Here there has been a deliberate importation of laborers by those who needed their labor; and, although the laborers have intended to return home after a few years' service, and are indeed under British regulations, supplied with return passage tickets, permanent settlements are likely to result, for the planters of Guiana, for instance, have little prospect of supplying themselves in any other way with the means of working their estates. The coolies would doubtless be brought to tropical Australia also, but for the dislike of the colonists to the regulations insisted on by the Indian Government; so instead of them we see that importation of Pacific islanders into North Queensland which is now a matter of so much controversy. Under very different conditions we find the more spontaneous immigration of French Canadians into the northern United States, where they obtain employment in the factories, and are now becoming permanently resident. At first they came only to work till they had earned something wherewith to live better at home; but it constantly happens that such temporary migration is the prelude to permanent occupation. So the Irish reapers used to come to England and Scotland before the migration from Ireland to the English and Scottish towns swelled to great proportions in 1847. The Italians who now go to the Argentine Republic less frequently return than did their predecessors of twenty years ago.

In all these instances the transfer of population due to a demand for labor has been, or at least has purported to be, a voluntary transfer. But by far the largest of all such transfers, now happily at an end, was involuntary—I mean that of Africans carried to America to cultivate the soil there for the benefit of white proprietors.* From early in the

* I do not dwell on the slave trade in ancient times, because we have no trustworthy data as to its extent; but there can be no doubt that vast numbers of barbarians from the west, north, and east of Italy and Greece were brought in during five or six centuries, and they must have sensibly changed the character of the population of the countries round the Adriatic and Ægean. Here of course there was no question of climate, but slaves were caught because their captors did not wish to work themselves. The slave trade practiced by the merchants of Bristol before the Norman Conquest and that practiced by the Turkoman, recently, resemble these ancient forms of the practice.

sixteenth century, when the destruction of the native Indians by their Spanish taskmasters in the Antilles started the slave trade,* down to our own times, when slavers still occasionally landed their cargoes in Brazil, the number of negroes carried from Africa to America must be reckoned by many millions. In 1791 it was estimated that 60,000 were carried annually to the West Indies alone. The change effected may be measured by the fact that along the southern coasts of North America, in the West India islands, and in some districts of Brazil the negroes form the largest part of the population. Their total number, which in the United States alone exceeds 7,000,000, can not be less than from 13,000,000 to 16,000,000. They increase rapidly in South Carolina and the Gulf States of the Union, are stationary in Mexico and Peru, and in Central America seem to diminish. Though some have suggested their re-migration to Africa, there is not the slightest reason to think that this will take place to any appreciable extent. On the other hand, it is not likely that they will, except, perhaps, in the unsettled tropical interior of the less elevated parts of South America, spread beyond the area which they now occupy. The slave trade is unfortunately not yet extinct on the east coast of Africa, but it has caused so comparatively slight a transfer of population from that continent to Arabia, the Turkish dominions, and Persia as not to require discussion here.

Before quitting this part of the subject a passing reference may be made to two other causes of migration, which, though their effects have been comparatively small, are not without interest—religion and the love of freedom. Religion has operated in two ways. Sometimes it has led to the removal of persons of a particular faith, as in the case of the expulsion of the Jews from Spain by Ferdinand and Isabella, the Catholic, an event which affected not only Spain but Europe generally, by sending many capable Spanish Jews to Holland and others to the Turkish East. Similar motives led Philip III to expel the Moriscoes in A. D. 1609. The present Jewish emigration from Russia is also partially, though only partially, traceable to this cause. In another class of cases religion has been one of the motive forces in prompting war and conquest, as when the Arabs overthrew the dominions of the Sassanid kings, overran the eastern part of the East Roman Empire, subjugated North Africa and Spain; and also in the case of the Spanish conquests in America, where the missionary spirit went hand in hand with, and was not felt to be incompatible with, the greed of gold and the harshest means of satisfying it. The latest American instance

*The first negroes were brought from Morocco to Portugal in 1442, soon after which they began to be brought in large numbers from the Guinea coasts. There were already some in Hispaniola in 1502; and after 1517 the trade from Africa seems to have set in regularly, though it did not become large till a still later date. Las Casas lived to bitterly repent the qualified approval he had given to it, in the interests of the aborigines of the Antilles, whom labor in the mines was swiftly destroying; but it is a complete error to ascribe its origin to him.

may be found in the occupation and government of Paraguay by the Jesuits. Finally, we sometimes find religious feeling the cause of peaceful emigrations. The case which has proved of most historical significance is that of the Puritan settlement in Massachusetts and Connecticut; among those of less note may be reckoned the flight of the Persian fire worshippers to Western India; the Huguenot settlements in Brazil and on the southeastern coast of North America, destroyed soon after their foundation by the Portuguese and Spaniards, and the later flight of the French Protestants after the revocation of the edict of Nantes; the emigration of the Ulster Presbyterians to the United States in last century; the foundation of various German colonies at Tiflis and other places in the Russian dominions.* Nor ought we to forget one striking instance of expatriation for the sake of freedom—that of the petty chieftains of Western Norway, who settled Iceland in the ninth century to escape the growing power of King Harold the Fairhaired.

III.—CHANNELS OF MIGRATION.

From this political side of our subject we return to its physical aspects in considering the lines which migration has tended to follow. These have usually been the lines of least resistance, *i. e.*, those in which the fewest natural obstacles in the way of mountains, deserts, seas, and dense forests have had to be encountered. The march of warlike tribes in early times and the movements of groups of emigrants by land in modern times have generally been along river valleys and across the lowest and easiest passes in mountain ranges. The valley of the lower Danube has for this reason, from the fourth century to the tenth, an immense historical importance, for it was along its levels that the Huns, Avars, and Magyars, besides several of the Slavonic tribes, moved in to occupy the countries between the Adriatic and the Theiss. While the impassable barrier of the Himalaya has at all times prevented any movements of population from Tibet and Eastern Turkistan, the passes to the west of the Indus, and especially the Khaiber and the Bolan, have given access to many invading or immigrating masses, from the days of the primitive Aryans to those of Ahmed Shah Durani in last century. So in Europe, the Alpine passes have had much to do with directing the course of streams of invaders to Italy. So in North America, while the northern line of settlement was indicated by the valley of St. Lawrence and the Great Lakes, the chief among the more southerly lines was that from Virginia into Tennessee and Kentucky over the Cumberland Gap, long the only practicable route across the middle Alleghanies.

* The Tiflis Germans left Würtemberg in order to avoid the use of an obnoxious hymn book. The Mennonites went to Southern Russia to escape military service, but the promise made to them by Catherine II has recently been broken, and they have lately been departing to America lest they should be compelled to serve in the Russian army.

Of migrations by sea it has already been remarked that owing to improvements in navigation, they have now become practically independent of distance or any other obstacle. In earlier times also they played a considerable part, but only in the case of such seafaring peoples as the Phenicians, the Greeks, and the Northmen,—instances in which the number of persons transferred must have been comparatively small, though the historical results were profound. Those which most nearly approach the character of national movements were the transfer of a vigorous Phenician shoot to Carthage, of a mass of Greeks to South Italy and Sicily, and of the Jutes, Saxons, and Angles to Britain.

The most important physical factor in determining lines of movement has, however, been climate. Speaking broadly, migration follows the parallels of latitude, or more precisely, the lines of equal mean temperature, and not so much, I think, of mean annual heat as of mean winter heat. Although the inhabitants of cold climates often evince a desire to move into warmer ones, they seem never to transfer themselves directly to one differing greatly from that to which they are accustomed; while no people of the tropics has ever, so far as I know, settled in any part of the temperate zone. There is one instance of a north European race establishing itself on the southern shores of the Mediterranean—the Vandals in North Africa; and the Bulgarians came to the banks of the lower Danube from the still sterner winters of the middle Volga. But in the few cases of northward movement, as in that of the Lapps, the cause lies in the irresistible pressure of stronger neighbors: and probably a similar pressure drove the Fuegians into their inhospitable isle.

The tendency to retain similar climatic conditions is illustrated by the colonization of North America. The Spaniards and Portuguese took the tropical and sub-tropical regions, neglecting the cooler parts. The French and the English settled in the temperate zone; and it was not till this century that the country toward the Gulf of Mexico began to be occupied by incomers from the Carolinas and northern Georgia. When the Scandinavian immigration began, it flowed to the northwest, and has filled the States of Wisconsin, Minnesota, and Dakota. And when the Icelanders sought homes in the New World, they chose the northernmost place they could find by the shores of Lake Winnipeg, in Manitoba. So the internal movements of population within the United States have been along the parallels of latitude. The men of New England have gone west into New York, Ohio, and Michigan, whence their children have gone still farther west to Illinois, Iowa, Oregon, and Washington. Similarly the overflow of Virginia poured into Kentucky and Tennessee, and thence into southern Illinois and Missouri; while it is chiefly from the Carolinas that Georgia, Alabama, Mississippi, Arkansas, and Texas have been settled. The present negro emigration from the eastern States of the South is into Arkansas and Texas. Oregon is the only Northern State that has received any con-

siderable number of immigrants from the old slave States; and western Oregon enjoys, in respect of its maritime position, an equable climate, with winters milder than those of Missouri.

IV.—THE LARGER SERIES OF MIGRATIONS.

Without attempting to present a chronological view of the principal migrations by which the population of the world has been shifted, I will attempt to indicate very briefly the main epochs at which these have been most frequent or most important. They may be classed in five groups, corresponding to five periods in the history of those parts of the world of which we possess a history. The first epoch covers prehistoric times, times known to us only by faint traditions and by the results of philological and archaeological inquiry. We are able to say that certain movements of races did take place before the date of our earliest written records, but unable to fix these movements to any point of time. Thus there is reason to believe that the Celtic races advanced from east to west, partly forcing into corners, partly fusing with, that earlier population of Gaul and Britain which is usually called Iberian, and of which the Basques are supposed to be representatives. Thus the Etruscans descended from the Alps into middle Italy, as the ancestors of the Latins and Sabellians would appear to have done at an earlier date. It seems probable that the Slavs and Letts came to the Oder and the Vistula from the southeast. Recent philological research lends weight to the view that the Phrygians and the Armenians, both races of the Indo-European family, were originally settled in southeastern Europe, and crossed the Bosphorus into the seats where authentic history finds them. At some remote but quite undetermined time Aryan invaders entered northwestern India, and slowly spread to the south and east from the Punjab; while, at a still earlier epoch, another race coming from the west passed through Beluchistan (where it has left a trace of its passage in the language spoken by the Brahuis) and moved southeastward into the Dekkan and southern India, in which its four great allied tongues, those we call Dravidian,* are now spoken by nearly 30,000,000 people. Nor have we any materials for ascertaining the time at which the Polynesian Islands were occupied by the two races, the brown and the black or negroid, which now inhabit them, and both of which seem to have come from the East Indian Archipelago, passing from isle to isle in their canoes against the trade winds that blow from the American coast. Finally, it is to prehistoric and probably to very remote times that belongs the settlement of the two American continents by immigrants from Asia, immigrants who appear to have crossed Bering Straits, or made their way along the line of the Aleutian Isles,† and thence to have slowly drifted southward from

* Tamil, Telugu, Canarese, and Malayalam.

† Some recent writers would refer the entrance of the present American races into their continent to a period so remote as that in which Asia was joined by dry land to America.

Alaska to Tierra del Fuego. That the process of settling these vast areas must have taken an enormous space of time is proved, not only by the archæological evidence drawn from human bones and other relics of primitive man, but also by the great differences, both physical and linguistic, between the various American races—differences, however, which are nowise incompatible with the doctrine of a common Asiatic origin.

The first migrations of which we have distinct historical evidence, besides those of the Phenicians and Israelites, are the movement of the Dorians into Peloponnesus and of the Æolians and Ionians to the west coast of Asia Minor. Somewhat later, in the seventh century, B. C., collisions seemed to have occurred among the nomad tribes to the north of the Black and Caspian seas, which led to the irruption of a people called Cimmerians, who advanced as far as Ephesus, and part of whom seem to have permanently settled on the south coast of the Euxine, and of a host of Scythians who ravaged Western Asia for many years, and were bought off by King Psammetichus on the frontiers of Egypt. Whether any permanent settlements followed these irruptions does not appear, but they are interesting as the first of the many instances in which the roving people of the steppe have descended on the settled States to the south, carrying slaughter and rapine in their train.

Passing over such minor disturbances of population as the Celtic occupation of North Italy and of that part of Asia Minor which from them took the name of Galatia, and passing over also the premature descent of the Cimbri and the Teutones into the Roman world in the days of Marius, who slaughtered them at Aix (in Provence) and Vercelli, we arrive at the third great epoch of movement—that which the Germans call *par excellence* the wandering of the peoples (Völkerwanderung). The usual account describes this movement to have begun from the nomads of Mongolia, living near the Great Wall of China, one tribe aggressing on or propelling another, until those who dwelt westward near the Caspian precipitated themselves on the Goths, then occupying the plains of the Dnieper and Dniester, and drove them across the Danube into the Roman Empire. Whether this was the originating cause, or whether it is rather to be sought in a lack of food and the natural increase of the tribes between the Baltic and the Euxine, there certainly did begin with the crossing of the Danube by the Goths, in A. D. 377, an era of unrest and displacement among all the peoples from the Caspian to the Atlantic, which did not end till the destruction of the Scandinavian power in Ireland at Clontarf, in 1014, and the rolling back of the great Norwegian invasion of England, at Stamford Bridge, in 1066. The Goths, the Vandals, Suabians, Burgundians, Franks, Saxons, Lombards settled in various provinces of the Roman Empire and founded great kingdoms. Minor tribes, such as the Alans, Rugians, and Herulians, moved hither and thither, without effecting

any distinct and permanent settlement. A vast multitude of Huns ranged across Central Europe, carrying destruction as far as the Seine. Various Slavonic tribes occupied the countries along the Danube and the east coast of the Adriatic; they even filled the isles lying off the Dalmatian coast (where only Slavonic is now spoken), and descended into Greece, in the modern population of which they form a large element. The Bulgarians, a Finnish people from the Volga, settled among the Danubian Slavs and adopted their language, while the Avars, penetrating farther west, held the great Hungarian plain for two centuries. Last of all, at the end of the ninth century, came the Magyars, another Finnish tribe, who retained their old language and have played a brilliant part in history. A century before they entered Hungary, the Norsemen and Danes had begun those piratical expeditions which ultimately turned into migrations, largely changing the population of eastern Britain and of northern France. At one moment the Northmen of Iceland seemed on the point of spreading from their settlement on the coast of East Greenland into North America, where they made descents at points the most southern of which have been plausibly conjectured to lie in Massachusetts or Long Island. These expeditions met with so much resistance from the natives that the idea of permanent settlement, apparently for a time entertained, was abandoned. The Norsemen had not, like the Spaniards five centuries later, and the English of the seventeenth century, the advantage of firearms, and they came from a very small nation, which could not afford to waste its men; so this case has to be added to that list of attempted colonizations which might, like the settlement of the Phocæans in Corsica and the Huguenots in Brazil, have changed the course of history had they but prospered. These seven centuries of unrest left no population in Europe unchanged, and gave birth not only to the states and nations of the middle ages and the modern world, but to modern civilization as a whole, creating new tongues and new types of culture from the mixture of the intruding races with the provincial subjects of Rome.

The fourth group of migrations overlaps in time that which we have just been considering, and in three countries overlaps it also in space—viz, in North Africa, in Spain, and in the Thraco-Danubian lands. But its origin was wholly distinct and its character different. It begins with the outbreak of the Arabs from their remote peninsula immediately after the death of Mohammed—we may date it from the first defeats of the Romans in Syria in A. D. 632, and of the Persian in A. D. 635—and it did not quite end till the cession of Podolia to the Turks, ten centuries later, in A. D. 1695. It changed the face of Western and Southern Asia, as the Völkerwanderung changed that of Europe, yet it involved far less transfer of population, and worked more by way of permeative conquest than of migration proper. The Arabs spread over Irak, Egypt, Syria, North Africa, Sicily, and the Iberian peninsula; twice they laid their grasp on the southeastern corners of Gaul.

Their new religion gave an Arab tinge to the literature and habits of Persia and Western Turkistan; its influence is strong to-day in the East Indian Archipelago and on the coasts of East Africa, as well as in the vast inland region from Timbuctoo to Somali Land. After their conquering force had fully spent itself, the initiative passed to the Turks, and an infusion of Turkoman blood and Musselman ideas helped to transmute the former subjects of the East Roman Empire in Asia and Europe into the so-called Ottomans of to-day. The wave has for two centuries been visibly receding. Since 1878 we have seen the Mohammedan Beys retiring from Bosnia as they retired thirty years ago from Servia; the Circassians, and still more recently, some of the tribes of Daghestan, have gone forth from their mountain homes; the Pomaks are beginning to leave Bulgaria; it is probable that in forty years more hardly a Musselman will be left on European soil, unless the jealousies of European powers should still keep the barbarian enthroned in Constantinople. Not less remarkable than the movement of the Arabs to the Oxus and the Tagus, and of the Turk from the Oxus to the Adriatic, was the movement of the races from beyond the Indus and the Hindu Kush into India. The irruptions which begin with the expedition of Mahmud of Ghazni in the eleventh century brought some of the mixed Central Asiatic races, who passed as Moguls, and a probably greater number of Pathans (Afghans) into Upper India, in parts of which they sensibly affected the character of the population. Here too, more was done in the way of assimilative influence than by an infusion of blood, for the Musselman bands carried their religion to the shores of the Bay of Bengal and far into the Dekkan; they introduced a new and splendid style of building and an exquisite richness of decoration; their deeds were recorded by the first regular chroniclers of India. In a fourth region, that of the countries north of the Black Sea, the irruptions of Zinghis Khan and his sons brought about some permanent changes. But it is doubtful how far the presence of such Tartar and Mongolic tribes as still remain in the Crimea and along the Volgo is due to those invasions; and since, whatever their consequences may have been, they are not due to Islam, for the Mongols were heathen, they do not fall within the group of migrations we are now considering.

The fifth group begins with the discovery of America in 1492, if we ought not rather to date it from the first long voyages of the Portuguese, opening with the passage of Cape Bojador in 1435 (under an English captain) and culminating in the rounding of the Cape of Good Hope and opening of the sea route to India, by Bartholomew Diaz in 1486, followed by Vasco de Gama's voyage to Malabar twelve years later.

Four great eras of settlements belong to this group. The first is that of the Spaniards and Portuguese in tropical America; the second is that which brings the negroes from Africa to America; the

third is the colonization of the temperate parts of the North American coast by the English, French, and Dutch in the seventeenth century; the fourth is the immense outflow from Europe, not only to America but also to Australasia, and—in a much smaller degree—to South Africa, an overflow mainly due to the progress of physical science: firstly, in introducing the use of steam for ocean voyages, and, secondly, in so accelerating the growth of population in Europe that the impulse toward less crowded lands became stronger than ever before. The scale of this outflow of the last seventy years has been far larger than that of any previous time, and has indeed become possible only because ocean transit is now so swift, safe, and cheap. The export of Chinese to America, and of Indian coolies to and fro in the tropics, is in like manner attributable to the cheapness with which they can now be carried for long distances, as well as (in the case of the coolies) to the increased demand for tropical products which the growth of population and of wealth in the north temperate zone has created.

V.—THE CORRELATIONS OF MIGRATION.

Among the many questions suggested by the facts we have noted, I will advert to two or three only.

One of these bears on the analogy between the migrations of mankind and those of other animals and of plants. If the majority of our geologists are right in holding that man existed in those very remote times in which great changes of climate were still taking place, the analogy must then have been close. Races of men may, in paleolithic times, have moved northward or southward, according to the recession or advance of the great ice sheet that once covered the northern part of the north temperate zone, just as we know that animals moved, and just as we find that certain species of plants have, in our latitude, sometimes occupied the low country, and sometimes retired to subarctic regions or ascended to the tops of the loftiest mountains. It has been lately maintained that the Eskimo of Arctic America are the descendants of the Cave men of Britain and France, driven north many thousands of years ago by the growing mildness of the climate. We know that changes in the level of the sea have produced revolutions in the fauna and flora of countries, not only by affecting the course of ocean currents, and thereby the climate, but also by bringing, when lands formerly separated became parts of the same continent, species from one land to another, where the incomers overpowered or expelled the old inhabitants, or became, under new conditions and through the struggle between competing species, themselves so modified as to pass into new forms. If man existed at a time so distant as that wherein Bering Straits and the North Sea and part of the Mediterranean were dry land, we may conjecture, from the influence of these physical changes upon the animal and vegetable world, what their

influence may have been upon him in causing tribes to move from place to place, and in bringing about alterations of racial types.

The geological record supplies ample evidence how greatly the species of animals and plants have transferred themselves from one dwelling place to another in distant ages. The horse, in his earlier forms, was abundant in America, but he vanished there, and had been long extinct when the Spaniards of Cortez won Mexico by the terror he inspired. The camel, it appears, was originally a New World beast, and the gigantic *Sequoia*, of California, a European tree. But it is seldom that we are able to fix the causes which have brought about these transferences. And even with regard to those comparatively few migrations of animals which have occurred within recent times it is seldom that any palpably operative ground can be assigned. The latest instance of any considerable migration, apart, of course, from the agency of man, is the invasion of Europe by the brown rat, a native, it seems, of East Central Asia, which has practically expelled the black rat from Europe, just as the latter has been ejecting weaker rodents from South America.

In prehistoric times the movements of animals must have frequently told upon man. It appears that some centuries before our colonists entered North America the buffalo had begun to move eastward from the prairie highlands in and near the Rocky Mountains toward the Mississippi; and in order to tempt him still farther eastward the Indians began to burn the forests which covered its banks and those of the Ohio River in what are now the States of Illinois, Indiana, and Kentucky. The abundance of animal food thus brought within their reach seems to have checked the progress of the tribes in the arts of sedentary life, throwing them back into the stage of hunters.

Since man, in his advancing civilization, has begun to domesticate animals and to understand how to improve the soil and make full use of its capacities, the chief transfers of animals and plants to new regions have been due to his action. He has peopled the New World and Australasia with the horses, cattle, and sheep of Europe, turning to account tracts which might otherwise have remained a wilderness. The trees he has brought from distant regions have sometimes grown to forests and changed the aspect of whole countries. Thus, the tops of the Neilgherry hills in Southern India have nearly lost their beautiful ancient woods, and are now, since the English took them in hand, covered with the somber *Eucalyptus* and *Acacia melanoxylon* from Australia, or with plantations of tea from China, or of quinine from Paraguay. The landscape of Egypt, as we see it, must be quite different from that which Moses or Herodotus saw; for most of the trees belong to species which were then unknown on the Nile. Many creatures and many plants have also followed man without his will. The rats which our ships carry, and the mosquitoes whose eggs lurk in the water barrels, find their way to land and plague new countries; the English sparrow is now a nuisance in North America, though less pernicious than the

English rabbit in Australia. Species of shrubs and herbaceous plants, the seeds of most of them brought accidentally from America or Asia, have thrice overrun the Hawaiian Islands, so that the present vegetation of the group is largely different from that which Cook found little more than a century ago. Thus the migrations of men, which nature once governed, have now come to be followed by those of other creatures, and are the source of many a change upon the face of nature herself.

VI.—INFLUENCES RESULTING FROM MIGRATION.

If we ask what has been the result of the changes we have been considering on the political organizations of mankind, and on the types of human culture, the answer must unquestionably be that they have become fewer and fewer. From the beginning of authentic history the process of reducing the number of tribes, of languages, of independent political communities, of forms of barbarism or of civilization, has gone on steadily, and indeed with growing speed. For many parts of the world our data do not go far back. But if we take the part for which the data are most complete, the basin of the Mediterranean, we find that now there are only nine, or at the most ten, languages (excluding mere dialects) spoken on its coasts, while the number of States, counting Montenegro, Egypt, Malta, and Morocco as States, is ten. In the time of Herodotus there must have been at least 30 languages, while the independent or semi-independent tribes, cities, and kingdoms were beyond all comparison more numerous. The result of migrations has been to overwhelm the small tribes and merge them in larger aggregates, while the process of permeation, usually, though not always, a sequel of conquest, has assimilated even those among whom no considerable number of intruders came. Sometimes the mere contiguity of the new and stronger race extinguishes the weak one, as in the case of the Tasmanian aborigines.* But more frequently the weaker is simply absorbed into and accepts the language and general type of the stronger, which is not necessarily the more gifted or the more civilized; and thus Britain has become Anglicized, the Celtic population retaining its languages and some of its distinctive marks only in western and mountainous corners; thus the Wends of North Germany have been Germanized, thus the Laps of the extreme north of Europe are being absorbed by the Norwegians, Finns, and Russians; thus some of the Albanian clans are being Hellenized; thus the Talains of Pegu are becoming merged in the Burmese, as possibly the latter may ultimately be in the Chinese. The remarkable thing is that neither this blending of races, nor the transfer of races to new climatic and economic conditions, tends to develop new types to anything like the same extent as

* So the Guanches of Tenerife soon disappeared as a distinct race, though some of their blood remains; so the Maories and native Hawaiians have become greatly reduced in numbers, and are likely to become before long extinct.

it destroys the old ones. The Crown is allowed to create one new Irish peerage for every three that die out. Nature uses her prerogative far more sparingly; she does not produce a new type for ten that vanish. Since the nations of modern Europe took their present distinct characters with their languages and their local seats between the sixth and the eleventh centuries, no new nation has appeared in Europe, nor is there now the least likelihood that any will. Neither has the settlement of European man in the New World wrought any marked changes in national types even when there has been a blood-mingling on a great scale. The average Mexican, who is by extraction more than half an Indian, is for most practical purposes, religious, social, and ethical, a Spaniard. The man of Pennsylvania or Ohio is still more palpably an Englishman, nor does the immense infusion of Irish and German blood seem likely to affect the Anglo-American type as it fixed itself a century ago. Nothing shows more clearly the strength which a well-established racial character has than the fact that the climatic and economic conditions of America have so little altered the English settlers in body, so comparatively little even in mind. Nothing better illustrates the assimilative power of a vigorous community than the way in which the immigrants into the United States melt like sugar in a cup of tea, and see their children grow up no longer Germans or Norwegians, or even Irish or Italians or Czechs, but Anglo-Americans. With the negroes, on the other hand, there is practically no admixture: and so far as can be foreseen they will remain, at least in the sub tropical parts of the South, distinctly African in their physical and mental characteristics for centuries to come. The same remark holds true of the white and black races in South Africa, where the process of blood mixture, which went on to some extent between the Dutch and the Hottentots, has all but stopped.

Will this process of extinguishing and assimilating the weaker nationalities and their types of culture continue into a distant future? Have those movements of population which have been hitherto so powerful a factor in that process nearly reached their limit? Since a time long before the dawn of history the various races seem to have been always in an unstable equilibrium, some constantly pressing upon others, or seeking to escape from crowded into vacant, from cold or sterile into more genial or more fertile, lands. Is the time near at hand when they will have settled down in a permanent fashion, just as our globe itself has from a gaseous state solidified by the combination of its elements into its present stable form?

Over large parts of the earth this time seems already within a measurable distance. Nearly all of the north temperate zone, except parts of southwestern and southeastern Siberia (especially along the lower Amour), and parts of Western Canáda, is now occupied, and most of it pretty thickly occupied. Districts there are which may be more closely packed: the Western United States, for instance, though

all the best land has already been taken up, can support a far larger population than they now have, and the same may be said of large tracts along the Alleghanies. But the attractions to emigrants become daily slighter as the conditions of agriculture grow less favorable through the inferior quality of the untouched land and the approaching exhaustion of that which has been tilled for two or three decades, not to speak of that vast natural increase of the population already on the spot, which intensifies the competition for employment. We may conjecture that within the lifetime of persons now living the outflow from Europe to North America will have practically stopped. A somewhat longer time will be required to fill not only the far less attractive parts of Northern Asia I have mentioned, but also such scantily inhabited though once flourishing regions as Asia Minor, Mesopotamia, and Persia, because a more torrid sun, and atrocious misgovernment, keep these regions, so to speak, out of the market. In the Southern Hemisphere, whose land area is far smaller, there are the temperate districts of Australia and South Africa, of which, so far as our present knowledge extends, no very large part has moisture enough to be available for tillage; while in South America there are La Plata, northern Patagonia, and the highlands of Bolivia, Peru and Ecuador.* The elevation above the sea of these latter tracts gives them a tolerable climate, but their wealth lies chiefly in minerals, and the parts which are both healthy and fit for agriculture are of comparatively small extent. There remain the tropics. Vast regions of the tropics are at present scantily peopled. Most of equatorial South America is a forest wilderness. Much of tropical Africa—where it is not condemned to sterility by the want of water—seems to have a population far below what it could support, owing not merely to the wars and slave raids which devastate the country, but also to the fact that peoples unskilled in tillage can not make the soil yield anything like its full return of crops. The same remark applies to Borneo, Celebes, New Guinea, Luzon, and some of the other isles of the Eastern Archipelago, among which only Java has as yet seen its resources duly developed. That there will be considerable migrations and shiftings of population among the races that now inhabit the tropics is probable enough. India (except the central provinces and Assam) and China are both filled to overflowing, and will doubtless continue to send out streams of emigrants which may in time fill up the vacant spaces in the Eastern Archipelago, perhaps in South America, perhaps even in Africa, unless some of its indigenous races should ripen into a greater capacity for patient and steady toil than any, except the Egyptian, has yet shown. But none of these tropical peoples, save the Chinese—for Japan lies outside the tropics—has a native civilization, or is fitted to play any part in history either as a conquering or as a thinking force, or in any

* The elevated parts of equatorial Africa are much smaller, though possibly large enough to support a European population of some few millions.

way, save as producers by physical labor of material wealth. None is likely to develop toward any higher condition than that in which it now stands, save under the tutelage, and by adopting so much as it can of the culture, of the five or six European peoples which have practically appropriated the torrid zone, and are dividing its resources between them. Yet the vast numbers to which, under the conjoint stimuli of science and peace, these inferior black and yellow races may grow, coupled with the capacity some of them evince for assimilating the material side of European civilization, may enable them to play a larger part in the future of the world than they have played in the past.

It is, of course, possible that the great European peoples, or some of them, may, after a few generations, acquire the power of thriving in the tropics, of resisting malarial fevers, and of rearing an offspring which need not be sent home to a cold climate during the years of boyhood. We may call it possible, because our experience is still too short to justify us in calling it impossible. But it seems so far from probable that in considering the future of the leading and ruling races of the world we must practically leave their permanent settlement in the tropics out of the question, and restrict our view to the two temperate zones. In these, as has been said, there is no longer room and verge for any great further removal of masses of men from one country to another. If, indeed, we were merely to look at a map indicating the comparative density of population in Northern Asia, Europe, and America, and see how much denser it is in the agricultural parts of France or Germany, for instance, than in Southwestern Siberia or the northwest of the United States and Canada, we might fancy the space remaining to be sufficient for many centuries to come. But if we were to compare such a map of to-day with a similar map of the world in 1780, and note how much of what would then have been marked as empty space, including all the vast area between the Alleghanies and the Pacific, has now been occupied, we shall realize the immense advance that has been made towards the establishment of an equilibrium of population and the relative shortness of the future during which we can look to emigration as a remedy for the evils which afflict the toiling masses of Europe. In this respect, as in many others, the world seems to be entering on a new era, whose phenomena will prove unlike any that have gone before.

It may be thought that as migrations have been a frequent cause of war in the past, the establishment of such an equilibrium will make for peace. But it must also be remembered that the pressure of each nation on its neighbors, and of the members of each nation on one another, tends to grow more severe with that severer struggle for subsistence which increasing numbers involve, and which, after a few more generations, the outlets that now still remain will no longer relieve.

THE "NATION" AS AN ELEMENT IN ANTHROPOLOGY.*

By Daniel G. Brinton.

The subject which I bring before you is one which I have selected in order to impress upon you forcibly the true breadth and full meaning of the science toward the cultivation of which we have assembled at this time.

There is no other word which so thoroughly expresses the purpose of this branch of learning as that which we have adopted—Anthropology, the science of man, the study of the nature of man, the search for and correct expression of those laws, and all the laws, which govern the birth, growth, development, and decay of all his traits, powers, and faculties.

Anthropology means this, and nothing less than this. Its motto is that of the character in the Terentian drama—

"*A me nullum humanum alienum puto.*"

It embraces everything and excludes nothing which pertains to humanity, whether in the individual or in his various aggregations. It omits no part or function of him as unworthy of its notice; it admits the existence of none so superior or sacred as to be beyond the pale of its investigations. The field which it goes forth to reap is the world, and its harvest season covers all time since man first set foot upon it.

It is signally unfortunate that the full connotation of the term has not been constantly present in the minds of those who have pursued the science. We should not then have witnessed the cheerless spectacle of one school of anthropologists claiming that man is nothing more than the highest mammal, and that the study of his anatomical and physiological relations exhausts the definition of their science, and that those who go beyond these are merely "historians and men of letters;" or that of another school, which, disregarding the incalculable potency of man's physical conditions, seeks to erect the science exclusively on the basis of the products of the mental faculties, his arts, institutions, religions, and languages.

*Presidential address before the International Congress of Anthropology at Chicago, 1893. (From proceedings of the congress, pp. 19–34.)

Each is equally in error. No correct and comprehensive idea can be formed of the various elements which have rendered man what he is, or any race or stock of men what it is, unless all these phenomena receive due consideration, and the various agencies which influence them are weighed with impartial fairness. The historian must become an anatomist, the anatomist a linguist, if he would reach positive results in this study.

You observe that the programme of this congress includes physical anthropology, archaeology, ethnology, folk-lore, religions, and linguistics. It would be an epoch in the history of the science, a notable era in its development, if the labors we are about to enter upon should lastingly impress on all who pursue this branch that every one of these departments is equally important, that not one of them can be neglected or overlooked, that the richest in results is still but *primus inter pares*, a brother among brethren.

To illustrate how closely the multitudinous influences which they represent are woven together, and how each bears upon the whole nature of man, I shall consider with brevity in what manner that entity which we call a "nation" appears as an element in anthropology. I have been partly, though by no means wholly, led to make this selection because this particular question has been much misunderstood in some quarters and its bearings misconceived. As late as at the congress at Moscow last year, a distinguished writer in our branch of science said, "Nationality has nothing to do with anthropology. It is a product of history and concerns history only."

So far from this being correct, I shall endeavor to show that nationality has ever been and is to-day an agent more powerful in modifying both the physical and the psychical elements of man than either race, climate, religion, or culture; and therefore that it must constantly occupy the attention of the anthropologist, whether his researches are in the purely physical or in the intellectual fields.

I desire to emphasize the fact that the anthropologist will never fully comprehend the science which he professes to follow, will never attain the preception of its whole significance, if he omits from its study, as not pertaining strictly to it, any influence whatever which bears upon and modifies in any direction the evolution of the human species. This the nation does with a directness and a potency which can not be misunderstood or called in question.

Let us inquire what it is we mean by the expression "a people" or "a nation," when we use these terms as synonymous. I can find no more profound and true definition than that given by the most philosophic English poet of this century, Robert Browning, in these words:

> "A people is but the attempt of many
> To rise to the completer life of one."

The incompleteness and imperfectness of the life of the isolated individual, and his conscious or unconscious aspirations for completion

and perfection, are the motives which have ever urged man to establish those relations with his fellows which result in what we call social ties or bonds.

Although to the superficial observer these seem to have been most heterogeneous and fortuitous, a comprehensive analysis reduces them to a very few so far as their guiding principles are concerned. Here as elsewhere in ethnology we are impressed with the paucity, yes, I may even say the poverty, of the resources which have been utilized by man in his upward march to conscious culture.

Wherever we find men united together under some form of social compact, we shall find also that this compact will fall under one of three categories. It is based upon community, either real or theoretical, of blood, of territorial area, or of purpose. These three forms are mutually incompatible; they are exclusive of and in sharp contrast with one another; they react very differently upon the individual and the race; and they belong markedly to different periods in the history of a people, to different stages of its advancement in culture.

It may be laid down as a rule with few or no exceptions that the earliest form of the social bond is one of blood, of kinship, of consanguinity and affinity. The unit of the primitive horde is the family; the one cohesive principle which it recognizes as socially binding is purity of descent, the maintenance of the integrity of the stock, as its members understand it. Here then we see a mighty influence at work to preserve in primitive times and conditions the unity of the physical type. The visible aim of communities in the lower stages of culture is to preserve at all costs the characteristics of the race to which they belong, and the particular traits of the variety of that race as inherited from their ancestors. This is the guiding principle of what is known as matriarchy and the custom of tracing the genealogical line through the maternal and not through the paternal ancestry. Positive certainty as to parentage must in every case be limited to the mother, and for that reason the female line always insures a higher probability of purity of descent.

Of course the degree with which the conservation of the type was really maintained under this system depended on the local laws or customs regarding marriage and the fidelity required of married women. It is true that in both these respects there is considerable divergence in early conditions. In some places exogamous marriages prevailed; that is, the wife must not be an acknowledged relation of the husband; more frequently, marriages must be endogamous, that is, she must be of his recognized kin; though often this again is limited, as that she must not be an offspring of the same mother, or not be within certain degrees of kinship. Reminiscences of these restrictions still prevail in civilized communities, in the laws prohibiting the marriage of near relations, or, as in England, prohibiting marriage with a deceased wife's sister.

In spite of these limitations, which differ widely in different tribes, the general influence of the principle of consanguinity as the basis of the social compact unquestionably aided through countless ages to individualize the physical types of the human species, and thus to develop and render permanent its races and varieties as we now know them.

So powerful was this prejudice in favor of the ancestral type, that it was a general custom in primitive times to destroy at or shortly after birth any aberrant types, and to bring all into accord with the tribal idea. For instance, in certain parts of Mexico there is a tendency to congenital albinism in the native population; and before the conquest all children displaying this tendency were sacrificed to the gods before the age of puberty. Among the Papuans, when a child is born of a lighter color than the average of the tribe, it is assiduously held in the smoke of green branches until it is tanned to the proper hue. Indeed, whenever there was any material variation from the received type, the infant was sure not to live to that period of life when he or she could transmit it to offspring; and thus a potent factor in the evolution of the species toward modified forms was absent throughout all the childhood of the human race, owing to the conditions of the prevailing social compact.

The somatologist will object to this, that in the very earliest times and within limited areas we find that a wide diversity of type prevailed. For instance, I suppose the oldest remains of the human race found up to the present have been unearthed in Western Europe. But these venerable relics show the existence there in remotest times and at no great distance apart (not more than a few days' walk of an active pedestrian), of men with broad heads, and others with narrow heads, with narrow faces and with wide faces, with expanded flat noses and with narrow aquiline noses, of stature below the medium and others above the medium; and we may reasonably conclude from their descendants that some were blonds with yellow hair, while others were swarthy brunettes with locks like the raven's wing. So that Prof. Kollmann, who has made this subject a special study, can not see his way clear to admit less than four different races struggling for the soil of Western Europe in pre-historic times.

Yet if we may judge from some historic data and all analogy, these ancient peoples, like all others, strove to retain in its purity the type of their ancestors by a social organization looking to that end.

Two customs prevail everywhere in primitive life which largely counteract the result of consanguine marriages; the one is adoption, the other concubinage. Usually, in their unceasing wars, the males of conquered tribes were killed and the women taken as captives, thus introducing through the females of another line the peculiarities of their variety or race.

In some instances however, the males were in part preserved and

adopted into the clans of the conquering tribe, either as members or as slaves. In either case they led to a modification of the ascendant type.

So varied were and are the customs and rules of primitive peoples in all these respects that it would be vain to attempt to establish a formula representing the degree in which the integrity of the racial or ethnic type was maintained; but the aim of their institutions being always and definitely this, we may be sure that they tended very positively to preserving the lineage undefiled, and to perpetuating the physical and mental traits of each community. When this did not occur, it was in contradiction to the theory of the social compact, and arose from ignorance of the natural conditions which insure perpetuity of type, or their disregard, owing to the cravings of individual appetite.

In entire contrast to all this are both the theory and the practice which we find in the next higher step in social relations, that which has for its basis a geographical or territorial concept.

In this, it is not the notion of kinship but that of country which is predominant. The patriot of this epoch fights no longer for his lineage, but for his land, not for his relations, but for the realm. He expresses in this the sentiment which actuates the nation, properly so called. Consanguine governments are tribal governments; with the birth of a genuine nationality, the family, the gens, the tribe, are all doomed to disappear, and with them the modifying influences they exerted on the race.

The intervening step between the tribe and the nation is usually said to be the federation, in which several tribes agree to forget their jealousies and unite in defense or offense. This condition is transitory, and I shall pass it by, in order to consider the direct influence of nationality on those elements of human nature which are the peculiar topics of anthropologic science.

The first object of nationality is unity, and this in the fullest sense of the term and in all the relations of national life.

Almost the very first of its aims is physical unity. A visible contrast between the inhabitants of different areas under one rule is suggestive to the legislator of a lack of harmony in other respects. The influence of a court, or of centralization generally, has ever been to disseminate throughout the realm one standard of physical beauty, as also one of costume and deportment; and this irrespective of how many discrepant varieties go to make up the body of the nation.

In this, as in all other respects, the chief efforts of the nation through its rulers are directed toward destroying those individual and tribal traits which forms of government based on consanguinity make it their chief end to cherish.

This contrast presents itself early. We find for instance that the native rulers of ancient Peru, the Incas, were accustomed, as soon as they had subjugated a new province, to deport large numbers of its

inhabitants to distant parts of their empire and supply their places with inhabitants of other tribes who had been long subject to their rule.

This plan of partial deportation and colonization was familiar to the Carthaginians, Romans, and other enterprising nations of the Mediterranean Basin, and explains to a large extent the constant blending of extreme physical types which the somatologist discovers in the remains from the oldest cemeteries around that great interior sea. We know by history and tradition that the "blond Libyans," the light-haired, blue-eyed natives of Northern Africa, tall and dolichocephalic, were transported in large numbers across the sea to the north, and settled among the smaller, swarthy, and brachycephalic tribes, whom we vaguely hear of under the names of Ligurians, Aquitanians, and Iberians.

Another physical lever which the nation, as distinct from the tribe, brings to bear on the physical traits of the species within its limit is its military organization. This is no longer classified by clans, or gentes, but is an army, with its soldiers drawn indiscriminately from all parts of its territory, and moving indifferently into all parts as occasion calls for. In earlier and more disturbed times, when social ethics were less regarded than to-day, the presence of large numbers of men cantoned and quartered upon the inhabitants, often exercising over them a brutal authority, led to constant commingling of race types and the gradual extinction of local peculiarities.

The influence which the nation as an anthropologic element exerts on language is one which demands our special attention. When it is rightly understood, much of that contest which has been going on for years between ethnographers, as to the worth or worthlessness of language as a guide in ethnography, will appear in a different light.

It is obvious that it would be consonant with the spirit of a gentile or consanguine society to preserve pertinaciously its own inherited speech, and to oppose any changes in it. But it is just as much in its spirit to desire to confine its own tongue to its own members and to look with jealousy on others than those of the true blood making use of it. Professional linguists in the American field are well acquainted with the prevailing unwillingness of the natives to give much information about their languages. They regard with suspicion and distrust inquirers into their own peculiar dialects; it is in the nature of a trespass upon private property. The federations of tribes never go so far as to attempt to establish linguistic or dialectic unity. Only incidentally and accidentally does one tongue partly encroach upon another one in this stage of society.

For this reason the linguistic classification in ethnography is a truly valuable one in all conditions of life where the consanguine rule prevails. The language is then a trustworthy guide of affiliation, both exclusively and inclusively, and the instances are extremely rare, if any indeed

exist, where one tribe had deliberately forced another to change its language as the condition of entering into an alliance.

The so-called "Empire of Anahuac," in Mexico, the organization of which had not wholly emerged from the consanguine condition, held as conquered and tributary many tribes of different speech, but had made no effort to impose upon any of them its own sonorous and beautiful language. On the other hand, Peru, which had reached a condition of national existence, exerted constant and strong pressure, as its historian, Garcilaso de la Vega, assures us, to crush and extirpate all other tongues throughout its domains than the Kechua, that spoken by the Incas and their congeners. It was declared to be the official language, and there was no hope for promotion for one not familiar with it. In this respect, those enlightened rulers of the Peruvian state displayed an insight into what constitutes the very strongest bond of national unity, which we here in the United States appreciate yet but imperfectly. It is within my own memory that the acts of assembly of my own State were issued in two languages, thus encouraging a long-existing linguistic discrepancy between the citizens of that commonwealth. Linguistic unity is the indispensable basis of national unity. When, as is the case with one of the present European empires, we hear of thirty-six different languages being current under one rule, we may be sure there is no real coherence in the nation.

The recognition of this fact, and the steady efforts directed toward the extermination of subordinate tongues and the substitution of a general or national one in their place, has led to the phenomenon of peoples of the same descent speaking different idioms, and those of alien origin expressing themselves through one and the same medium.

It remains true nevertheless—and this is an important point too often lost sight of in the discussion—that this substitution of one language for another never takes place without an extensive admixture of blood; for there is no more potent and prompt method of attacking the integrity of a language than by inter-marriage. Indeed, except in cases of slavery, we may almost establish the formula that the admixture of blood under such circumstances bears the fixed relation of one-half to one; that is, that when a language has superseded another, one-half of the marriages in the latter have been with members of the former. Of course, by marriages in this relation we mean continued sexual unions, not necessarily legal ceremonies.

Whatever the national form of government adopted, the principal maxims of jurisprudence and the ethical principles upon which they repose are profoundly modified by the substitution of the national in place of the tribal idea.

I will illustrate this contrast by an example familiar to the students of the early history of this country.

The European settlers in the colonies of Pennsylvania and New York could not understand why, when in time of peace an Indian murdered

a white man, they could obtain no redress from the tribal government with whom they had treaty relations. They regarded such indolence a breach of faith and proof of evil intention. It was nothing of the kind. A crime of blood was something which concerned the consanguine gens only; it was a family matter with which the tribal council had no concern and about which it could take no action; it was in no sense a crime against the commonwealth.

This view of the case was something wholly incomprehensible to the Europeans, who belonged to states where a felony or a breach of the peace is an attack on the community. In other words, ethnic jurisprudence is something quite different when the nation appears on the stage of history from what it is in the tribal condition.

This contrast runs through the whole of ethics. In a thoughtful article, published some years ago in the *Zeitschrift für Ethnologie*, Dr. Kulischer pointed out that in primitive conditions ethics presents a dualistic aspect: It demands the cultivation of kindness, protection, assistance, love, and peace to our friends, but quite as much does it prescribe hatred, enmity, robbery, murder, and deception toward our enemy. The nation breaks down the walls of narrow tribal animosities; it increases the number of those whose patriotic interests are in common, and thus widens the area of duty and the conceptions of ethics; but who dares say that our own conceptions of ethics are much beyond the primitive stage when still the greatest hero among us is the most skillful in murdering men—the most expert military commander?

Anything like a categorical imperative in ethics, a prescription of duty which should be the law of everyone toward all men would be out of the question in a society based on relationship or on narrow territorial considerations.

Nowhere does this ethical contrast become more apparent than in the relations of the one to the many, of the individual to the mass, a feature in ethnic jurisprudence admirably brought out in his recent masterly work on the subject by Dr. Albert Hermann Post.

In the tribal, totemic, or consanguine condition of government the individual is not regarded as an independent unit. The obligations he has to fulfill are those of his gens, and his actions are regarded, not as his own, but as those of a member of his gens.

If he robs or murders, the punishment falls, not on him personally, but on the gens; and if blood money or other compensation is demanded, it is not from him that it is required, but from the gens.

He in turn is liable for any crime his fellow-clansmen may commit; and in this vicarious expiation he sees nothing in conflict with the principles of abstract justice. He has not yet reached to the consciousness of himself as an individual. He accepts the obligations of his clan as his own, and is scarcely aware that he suffers any diminution because he can create no obligations himself otherwise than in his position as a representative of the clan or gens.

This is also true of his civil rights and those which refer to property. Wherever the consanguine theory is in force, the communal idea of property is also active. The land belongs in part or in whole to the kith and kin, in the nature of common land, or is sublet by the heads of the community on longer or shorter tenures. Personal property is so only in the sense that it belongs to the members of an immediate family or subgens, not to an individual, and in many instances passes in the female line.

It is obvious that in such a condition of society no idea of independent personal duty or individual morality could rise in the mind; and should any such enter through foreign instigation, it would be condemned as false, destructive, and treasonable.

Permit me to dwell on this point with some detail because of its prime importance. Those considerations which establish in a community its moral code, its ideal standard of what is right, of conscience, and of duty, pronounce the final sentence on the fate of that community. In all earlier conditions the preservation of the gens or tribe rested more on measures of destruction than of protection. Hence, toward the alien and the stranger justice and mercy were out of place and actually prohibited. Cæsar tells us of the ancient Germans, (and Nordenskjöld repeats the same of the modern Tchuktches of Siberia,) that they respected no law of honesty in dealing with strangers or those alien to their tribe. To cheat such in trade, to deceive and to plunder them, was actually meritorious.

In such communities the stranger has no rights, and can claim no protection as a fellow human being. He can only attain such through some rite of adoption into the tribe, or through some ceremony by which he can claim the privileges of hospitality—what German writers call the *Gastrecht*. The gens, the clan, the tribe, is an isolated unit, in natural antagonism to the race at large, and recognizes no sort of solidarity with its other members, nay, regards them as foes.

How different is all this in the developed system of the state? There the individual man is held accountable for his own actions. He is considered responsible for the deeds he commits and, therefore, feels that he is answerable to himself for the opinions and ethical theories which lie at the basis of his life and direct his conduct. For the first time in the history of the race he learns the meaning of *personality*, the highest lesson which advancing civilization can impress on humanity. He sees that by himself he must either stand or fall; that no vicarious expiation can meet the demands of what is eternally right; that his responsibility does not belong to another, nor can it be involved by the actions of another, but ever centers in his own thoughts and actions. Thus is he gradually emancipated from that condition of tutelage and hereditary bondage in which he was so long kept by the consanguine theory of government.

I can not too strongly impress upon you that this concept of person-

ality is a totally different condition from that of the isolated primitive man. We may imagine such an one, living alone with his one wife, his children around him, his household goods and gods all within his lonely lodge. That man's monogamy, his sense of property, his feelings of duty and responsibility, of association and independence, can in no way be assimilated to those of the man who is the free product of the state, developed through countless generations of gradual culture. To the scientific anthropologist the one is the complete contrast to the other; they have nothing in common but their external membership of the same species and a vague resemblance of external conditions.

The individual is indeed the true purpose of the state. Its aim distinctly is that he, or she, as an individual, shall be provided with, and protected in, the greatest possible amount of personal liberty; in this being in the utmost contrast to consanguine governments, where the individual is nothing, the tribe everything.

The value of personal liberty is as a means toward the acquisition of personal happiness, and hence we are willing to accept the definition of the modern idea of justice as advanced by the eminent French anthropologist, André Lefèvre—that it is the respect for every interest which contributes to the highest general happiness of humanity; and we can not refuse to accept the definition of morality which Hovelacque and Hervé offer, as the only one which anthropologists can recognize; that it is the principle of organization for the purpose of satisfying the physical and intellectual needs of all men; a principle which they justly add, can only be carried out successfully by guaranteeing to the individual the highest degree of personal liberty in every direction, limited by no other barrier than the enjoyment of similar liberty by every other individual.

It is obvious on very slight reflection that the state as an element in anthropology has by no means worked out its full destiny in modifying the physical and psychical nature of man. As a form of government it is far from covering the whole of the earth's surface, and where it is nominally present it is still further in many instances from that perfected condition in which it has thrown aside the clogs and fetters of the consanguine system to which it succeeded.

Take the vast Empire of China for instance. It is ruled by a foreign dynasty on general principles of statecraft. But throughout all the really Chinese portions of the empire the details of the family system are retained with wonderful tenacity.

But we need not go so far for examples. Wherever we find a system of castes or of privileged classes, an hereditary nobility, or a state church, a transmissible community of property, whether real or personal, any inequality in the rights and responsibilities of sane adult individuals before the law, any concessions which relieve classes, or persons, or sects, or societies, or sexes of their full measure of liability, or confer upon them privileges or deny them rights enjoyed by others, there we

are in the presence of a form of government still clinging in these respects to the primitive theories of human society. The student of ethnological jurisprudence will class it to this extent with the totemic and gentile systems of the lower and earlier strata of human development.

Let me illustrate this by the relative position of woman in a tribe and in an enlightened State. I could not touch upon a weightier question to the somatologist, for none other so intimately relates to physical anthropology.

In spite of the matriarchal system, woman in all lower conditions of society is treated as inferior to man and is deprived of many rights which he enjoys. The exceptions to this are extremely rare, if any really exist. The cause of her inferiority is solely her less physical powers; it has ever been because she is bodily the weaker. The forms of marriage have made no difference. Whether a man could legally take to himself a multitude of wives, or whether, as in Thibet to-day, a woman could legally take a multitude of husbands; whether she was bought openly in the matrimonial market, or whether, as in this country, she could pick and choose at will from all her admirers; whether polygamy or monogamy prevails she has ever been treated as man's inferior, disallowed equal rights, prevented from equal liberty. So it remains to-day, though with some improvement.

At first she was but a slave and a beast of burden; at present, so far as the enjoyment of civic rights in modern states is concerned, she has risen to be classed among idiots and children. Surely we may hope that she has not yet attained the acme of her evolution.

A peculiar interest is attached to the development of this inquiry by the fact that it was originally an American contribution to our science. The first who clearly pointed out the distinction between gentile and political conditions of society, that is, between the tribe and the state, was the late Mr. Lewis H. Morgan; and, although we have been obliged materially to modify many of his opinions, to him belongs the credit of being the earliest to present in scientific form this important truth in anthropology. He did not perceive very clearly its bearings on physical anthropology, to which I have referred above, but he was fully awake to the potent agency of the state, as distinguished from the tribe, on the psychical nature of man. The following sentence from his chapter on the evolution of Greek culture will show this:

"That remarkable development of genius and intelligence which raised the Athenians to the highest eminence among the historical nations of mankind occurred after they had adopted democratic institutions, and these gave its inspiration."

By "democratic institutions" Mr. Morgan meant the substitution of a national for a tribal life.

But it would be an error to consider the state as we now know it, even in its best examples, as the final form which this element will

take in molding the body and the mind of man, his aspirations and his ethical instincts. Already there are evident signs that at no very distant future the human race will outgrow the limits of nationality and will demand and find some guiding principle which will break down the barriers which the nation, under present conditions, must perforce erect around itself; which will do away with the latent hostility which now requires the maintenance of enormous military establishments, and will successfully solve the problem of absolutely conserving the rights of the individual without impairing the efficiency of the organization.

It is easy to predict from what direction and under what impulses this desirable result will be brought about. Every year is making it clearer to the eye of the attentive observer; and never anywhere or at any time has there been in the history of humanity a grander example of its growth and potency than here, at this moment, we have spread before our admiring gaze. It is by means of international action, through associations and organizations formed for international purposes, that the highest and ultimate efficiency of government will be reached; and then it will be discovered to be one with anthropology, the science of man, the discovery of the laws which will lead him to the utmost symmetrical development of all his faculties, to his maximum efficiency, to his highest happiness.

SUMMARY OF PROGRESS IN ANTHROPOLOGY.

By Otis Tufton Mason.

GENERAL ANTHROPOLOGY.

Comprehensive works.—No great work appeared in 1893 in which a distinguished anthropologist summed up the results of his studies upon the whole subject of the natural history of man. The annual address of the president of the Anthropological Institute of Great Britain and Ireland brings together the work done by that society in an orderly manner, and a lecture bureau course of instruction was given by specialists through the United Kingdom under its auspices.

The Anthropological Society in Washington conducted successfully twelve Saturday lectures by distinguished specialists, covering the ground of the whole science. Dr. Brinton, in Philadelphia, also continued his comprehensive course. In most German universities there is some one professor who delivers an encyclopaedic series of lectures on anthropology.

During the year the program of the École d'Anthropologie in Paris was as follows:

Medical geography. M. Bordier.
Anthropogeny and human embryology. M. Duval.
Ethnology. Georges Hervé.
Linguistics and ethnography. André Lefèvre.
History of civilizations. Ch. Letourneau.
Zoölogical anthropology. P. G. Mahoudeau.
Physiological anthropology. L. Manouvrier.
Comparative ethnography. A. de Mortillet.
Prehistoric anthropology. G. de Mortillet.
Geographic anthropology. Fr. Schrader.

These lectures are of the highest order, and are recognized by the minister of public instruction as of general utility.

In the New Standard Dictionary just issuing by Funk & Wagnalls, of New York, as much attention is paid to words in this department of knowledge as in any other. Cassell, Johnston, the old reliable dictionaries, in their new editions, at last recognize the importance of this science.

The classification of anthropology in the British Association's Notes and Queries into anthropography and ethnology takes the last named term out of the realm of biological anthropology and places it at the head of all the functional sciences of man.

Societies.—The name of societies organized for the study of man alone is legion. Add to this the sections of academies and institutes of general science that have for their aim the study of whatever concerns man, and with this combine the work of other special societies that bear in some fashion upon this latest of sciences, and the general student becomes bewildered. These societies publish journals, bulletins, proceedings, memoirs, and even periodicals.

Not satisfied with home societies, students in every enlightened country combine in stated assemblies. Of these the chief are: International Congress of Anthropology and Prehistoric Archaeology, held in 1893 in Moscow; Society of Americanists; Congress of Anthropology at the World's Columbian Exposition, and the German Society of Anthropology, held annually.

Furthermore, each national association for the advancement of science has a section of anthropology. To these belong Section H, American Association for the Advancement of Science; Section of Anthropology in the British Association; Section of Anthropology in the German Society of Naturalists and Physicians; Section of Anthropology in the French Association for the Advancement of Science. And, of especial interest, the colonies of Germany, France, and England have organized associations in the Orient based on those at home.

At the American Association for the Advancement of Science the chief contributions to anthropology were as follows: The Biloxi Indians of Louisiana, vice-presidential address by the Rev. J. Owen Dorsey, showing them to belong to the Siouan stock: The lecture of Dr. Brinton upon "Early man," assigning to the human race as its birth-place the mountainous zone extending from the western foot-slopes of the Alps through the Himalayas nearly to the borders of the Yellow Sea: The paper by Prof. W. H. Holmes on "Primal shaping arts;" the phenomena of the shaping arts are classified by materials, processes, function of the product, culture stage of the artist, by order of development, and by peoples or races.

The shaping art is set forth as follows:

1. Fracturing processes
   - *a.* Breaking.
   - *b.* Splitting.
   - *c.* Flaking.
   - *d.* Chipping.
2. Battering processes
   - *a.* Bruising.
   - *b.* Pecking.
3. Abrading processes
   - *a.* Grinding.
   - *b.* Rubbing.
   - *c.* Polishing.
4. Incising processes
   - *a.* Cutting.
   - *b.* Scraping.
   - *c.* Picking.
   - *d.* Piercing or boring.

These processes and the order of evolution of the processes involved were shown in diagrams. The most excited discussion was with reference to the paleolithic problems. Other important communications were:

Navajo songs of sequence. Dr. W. Matthews, U. S. A.
Argillite quarries near Delaware River. H. C. Mercer.
Indian migrations. C. Staniland Wake.
Sense of taste among Indians. E. H. S. Baily.
Caches of the Saginaw Valley. H. I. Smith.
Is polysynthesis characteristic of American languages? I. N. B. Hewitt.
Psychology at the World's Fair. J. Jastrow.
Evidence of glacial man in America. G. F. Wright.
Antiquity of man in America. W. J. McGee.
Sheet copper designs, Hopewell group. W. K. Moorehead.
Mexican calendar system. D. G. Brinton.
Necropolis of Ancon, Peru. G. A. Dorsey.
Indian names of Four Winds. J. O. Dorsey.
Ceremony of the Quichua Indians. G. A. Dorsey.

The French Association met at Besançon. In the section of anthropology the following papers were of general scope:

Proportional weight of the cerebellum, the isthmus, and of the bulb. L. Manouvrier.
Prehistoric Algiers. P. Pallary.
Ancient and modern weapons of South American Indians. Felix Regnault.
The highest and the lowest natality in France; natality and masculinity; endogamy in rural districts. M. A. Dumont.
On the Ligurians. M. Ploix.

In June, 1893, the Societa Romana di Antropologia was organized in Rome, with one hundred founders. The society will devote itself to the science of man in all of its branches. Prof. Guiseppe Sergi, author of Principles and methods of classifying the human race, and Systematic catalogue of the varieties of man in Russia, was made president. Florence boasts still of the most efficient anthropological society in Italy.

At Moscow, during the first three weeks in August, the scientific people gave themselves to entertaining congresses, to wit: The International Congress of Anthropology and Prehistoric Archaeology, eleventh session, and The International Congress of Zoology, second session. Even in the last-named, papers were read that were of interest to anthropologists, such as Psychophysical study on the memory of sensation, by N. Savélier, and study of the repartition of animals in vertical contours.

Before the Congress of Anthropology many communications of general interest were made.

Prehistoric researches in Spain. L. Siret.
The populations of the Caucasus. E. Chantre.
Changes in the problems before the Congress. R. Virchow.
Sculpture in France in the stone age. Baron A. de Baye.
Kourgans of the Kirghiz Steppes. Ph. Nevedov.
Oriental origin of the Cloissonnée jewelry and its introduction into the West by the Goths. Baron A. de Baye.

Anthropological types of Great Russia. N. Zograf.

Anthropometry on the living as practised in Russia. N. Zograf.

Influence of race and hygienic and social conditions on the physical development of man. E. Dementeer.

Anthropometry of Transcaucasian peoples (3 pls.). E. Chantre.

Temperament, from a psychologic and anthropologic point of view. N. Zéeland.

Two anthropological types of the family; a study in heredity (8 pls.). I. Orchansky.

The Mongoloids of Siberia, their actual condition and their aptitude for civilization. N. Iadrintsef.

The primitive inhabitants of the Mediterranean. G. Sergi.

Cannibalism and human sacifice among the ancestors of the eastern Fins. I. Smirnov.

The World's Fair Congress of Anthropology at Chicago was opened with an address by the president, Dr. Brinton, on "the nation as an element in anthropology."* Papers on physical anthropology were read by Franz Boas, Gerald M. West, and Manuel A. Muñiz; on ethnology communications were made by Dr. Brinton, Walter Hough, Miss Fletcher, Carl Lumholz, and O. T. Mason. Dr. Brinton affirmed that no good evidence exists of contact between America and Asia in pre-Columbian times, but this was denied by Prof. Mason. Miss Fletcher's essay on Omaha music was a defense of the opinion that the musical scales of civilization are found in savagery in an undeveloped state. Mr. Mason's paper was a résumé of American aboriginal tools, uses of natural power, metric apparatus, mechanics, engineering, and machinery.

In archaeology, the leading paper was by Mrs. Zelia Nuttall on the Mexican calendar system, elaborately set forth in a series of charts.

Communications on folk-lore and religion were made by W. W. Newell, Franz Boas, J. Walter Fewkes, G. F. Kunz, Morris Jastrow, Mrs Sara Y. Stevenson, and Mrs. Matilda C. Stephenson.

One of the most instructive performances at the Congress was the explanation of exhibits and visits paid by invitation to the various parts of the grounds.

The Columbian Historical Exposition in Madrid was so far a success that there was brought together in the new national library and museum building the greatest collection of Americana ever under one roof. The Smithsonian Institution and many bureaus of the Government in Washington, the great museums of Philadelphia, New York, Boston, and Cambridge, and especially the Hemenway expedition, were well represented. Besides, all the Latin American States sent their treasures to complete the exhibition. Most of the valuable collections appeared again in Chicago.

Museums.—The museum idea was prominent in the minds and the publications of the World's Columbian Exposition during its entire progress. Prof. F. W. Putnam, who was appointed general manager of the department of anthropology, made most extended collections with this end in view. The result was most gratifying. Not only was

* This paper is printed in the present volume.

provision made for a museum at the new University of Chicago, but the citizens, led by Mr. Field with the munificent gift of $2,000 000, provided for a great museum in Jackson Park. To this will be attached a department of anthropology, including arts, physical anthropology, ethnology, and archaeology. The material is greater than that upon which any other institution of the kind was ever founded. Other museums in the United States were greatly helped by the Exposition, the Peabody Museum in Cambridge, the Natural History Museum in New York, especially with the Emmons collection from southeast Alaska, the National Museum in Washington, and the collections in Philadelphia. There were also many private cabinets formed and enriched from the same source. It is fair to say that anthropology in America has never before had its activities so stimulated and increased.

The development of laboratories for anthropological study, research, and instruction is slow. Physical anthropological apparatus will be noted further on. But, there could scarcely be said to exist in the world prior to 1893 a single building or institution where the material had been set out to teach the whole history of mankind or the whole round of anthropological science. Therefore the assemblage of objects to illustrate anthropology toward which the eyes of students turned in 1893, was the World's Columbian Exposition. The material of the science manifested itself there in the following forms:

(1) Representatives of living races in native garb and activities.

(2) Things or objects connected with every phase of human life.

(3) Pictorial representations of apparatus of life in action and repose.

(4) Books and descriptive publications, throwing light on man and of his inventions.

These exhibits were under the following auspices:

(1) The exposition authorities, under the lead specially of Prof. F. W. Putnam, aided by Prof. Sargent, Dr. Franz Boas, Dr. C. S. Wake, Miss Alice Fletcher, Mrs. Zelia Nuttall, Mr. Stuart Culin, Mr. W. K. Moorehead, Dr. West, Mr. G. A. Dorsey, and a large corps of army and navy and civilian assistants who travelled especially over the countries involved in the Columbian period.

(2) The Government of the United States, in the Government building especially installed by the Smithsonian Institution through the National Museum, the Bureau of Ethnology, and other Departments.

(3) Foreign and home exhibitors, in the foreign government buildings, in the exhibits from abroad and from home through all the great public structures.

(4) Concessionaires in the Midway Plaisance and also in the bazaars everywhere throughout the grounds. Indeed, it would not be too much to say that the World's Columbian Exposition was one vast anthropological revelation. Not all mankind were there, but either in persons or pictures their representatives were.

Every technical, artistic, industrial thought that had ever entered human minds could be seen in their primitive or in their most eloquent expression. From the rude human habitations about the anthropological building to the results of co-operative architectural dreams which constituted the White City, was a long way on the road of evolution in the builder's art. The same would be true of the arts of dress, adornment, food, rest, transportation, manipulation, and manufacture, commerce and exchange, heating and illumination, mechanics and mechanical forces.

The forlorn savage woman depicted on the doorway of the Transportation building at one end of a series of weary burden bearers was in strange contrast with the spirituelle paintings of angels on the walls above her head. But this was only one of a series of transformations which made the Chicago Exposition the most imposing anthropological exhibit the world has ever seen. The financial panic that seized the world prevented many thousands of scholars from studying the exposition and put back the science of man quite as much as it did his material progress.

Professor Putnam's department of the Exposition included all subdivisions of anthropology. It embraced (1) the ethnographical exhibition of native American peoples living in their native habitations on the grounds; (2) a general ethnographic exhibit in the building; (3) an archaeological exhibit in the building and casts of ruins in Yucatan shown outside; (4) exhibit of ancient religions, folk-lore, and games; (5) anthropological laboratories devoted to physical anthropology, criminal anthropology, psychology, and neurology with apparatus and diagrams; (6) an anthropological library in all branches of the science.

The anthropological exhibit of the Government was devoted (1) especially to showing the relation of the material activities of North America to the linguistic classification that had been recently completed; (2) to the exposition of the recent explorations made by Prof. William H. Holmes in quarry sites of the aborigines in various portions of the Union. This was done in a most creditable manner; (3) a synoptical view of the early history of mankind from the earliest stone age to the first iron age, set out by Professor Thomas Wilson.

Of great public interest among the foreign exhibits were the armor in the German village, the gold work from Colombia, the Turkish and the Cairene bazaar, the Java village, the Samoan village, the Dahomey village, the Japanese and the Hindoo bazaars. Indeed, only an extended catalogue will reveal the riches of the material.

Current literature.—Very frequent inquiries are made by those who wish to look up some special question or to begin some new study in anthropology. It is no longer possible to prepare for this summary a creditable bibliography in the space assigned; but it is also not necessary. Students who have access to the following publications

do not need any further help in following up the literature of the science:

(1) *The American Anthropologist*, Washington; quarterly; Judd & Detweiler. Extended bibliography on all studies relating to man.

(2) *The Index Medicus* and the *Index Catalogue* of the Surgeon-General's Office, Washington, especially thorough in anthropo-biology.

(3) The catalogues of the Literary Bureau, Boston.

(4) *Archiv für Anthropologie*, Braunschweig; quarterly. Most exhaustive lists, with short digests of books and papers.

(5) *Mittheilungen der Anthropologischen Gesellschaft in Wien.* Full bibliographies.

(6) Annuaire des Journaux, etc., Paris, 1892.

Mr. G. W. Bloxam has placed anthropologists under lasting obligations to him by his printing a complete index to the publications of the Anthropological Institute of Great Britain and Ireland (1843–1891). This includes also the journal and transactions of the Ethnological Society of London (1843–1871), the journal and memoirs of the Anthropological Society of London (1863–1871), the Anthropological Review, and the journal of the Anthropological Institute (1871–1891).

General literature.—The literature of the world has become impregnated with anthropology. *Science*, *The American Naturalist*, and especially *The Popular Science Monthly*, in America, give a large share of their pages to this topic. *Nature*, *The Academy*, *The Athenæum*, and all the great quarterlies of London: *Revue Scientifique* in Paris; *Globus* and a host of other journals in Germany, are common carriers of the best kind which send weekly, monthly, and quarterly cargoes of information to intelligent readers.

The gallery of anthropology is still in the future. At the World's Columbian Exposition, as mentioned, groups of lower races in costume were well set up, and photography was efficient in putting life into accounts of peoples inaccessible to the most of us. Gabriel de Mortillet has advocated the extension of the work of the camera, and im Thurn makes a good argument for its use in South America.

There is no good guide to anthropological studies published in America. The reprint of the *British Notes and Queries* was a timely piece of work by the British association.

ANTHROPO-BIOLOGY.

The sources of information concerning the biology of man are, first of all, the organs of the anthropological societies. In Germany and France far more attention is paid to craniology, measurement of the other parts of the body, the teeth, comparative anatomy of man and the lower animals, and greater stress is laid upon the importance of these studies. In England and the United States craniological measurements are discounted. All the literature of this branch of the science may be sought in the bibliographies of Surgeon-General's

Index-Catalogue and the *Index-Medicus*, Washington; the *American Anthropologist*, Washington; *Archiv für Anthropologie*, Braunschweig; *Mittheilungen der Anthropologischen Gesellschaft in Wein.*

Dr. Brinton, in *Science* (February 24), enters a vigorous protest against the multiplication of jaw-breaking compounds of Greek roots to represent different cranial measurements and indexes.

Craniologists have differed in opinion concerning the orientation of the skull for the purposes of measurement. All agree that it should be set as in life where the owner is looking straight ahead. To set up the skull after death in the position of the living head gazing at the horizon is the problem. Dr. Eugene Hirtz to this end has utilized the cadaver as an intermediary between the living and the skeleton, since the eye remains fixed in its orbit after death. The paresis of the muscular system is then complete—the eyes are immobile. The problem is to compare the visual axis of the cadaver with the plane of the cranium as used by the experimenter and with the gaze of the living fixed on the horizon. The conclusion is that the "orbital axis" of Broca is nearly parallel to the plane of the visual axes, or the so-called horizontal plane of the living. (*Bull. Soc. d'Anthrop. de Paris*, 4 s., IV, 386–389.)

Dr. Manouvrier, who has devoted years to the study of the long bones of the human body, communicated to the Paris Anthropological Society a memoir on the morphological variations of the body of the femur in the human species. The conclusion reached is that platycnemy, retroversion of the head of the tibia, and platymetry, seen in prehistoric remains, in savages, and among modern Europeans, do not represent anatomical survivals through atavism, but are all derived through physiological causes, allied to the kind of life and different external conditions susceptible of exaggeration or modification. (*Bull. Soc. d'Anthrop. de Paris*, 4 s., IV, 111–144.)

MM. Azoulay and Regnault have made a comparison in the comparative form of the incisors of apes and the various races of men. In the apes the outer enameled surface is wide and shaped like a hoe, of the uncivilized races the edges are more nearly parallel, and in the civilized races they are quite so. Measures were taken of the length of the free border and of the side of the enamel and the difference noted. The order of succession, as regards the elongation and rectangular form of the enamel, is: apes (chimpanzee and gorilla), negroes, New Caledonians, Australians, Polynesians, Javanese, Annamites and Chinese, Europeans, Indians, Bengalese. (*Bull. Soc. d'Anthrop. de Paris*, 4s., IV, 267–269.)

Prof. Cope some years since affirmed that the tubercular forms usual in the cusps of human molars point to a reversion to the lemurian dentition. In *Anatomischer Anzeiger* (No. 24, 1892), Dr. H. F. Osborn, of Columbia College, presents the result of his own researches, with a summary of other work, since Cope. The primitive mammalian molar is a single cone, to which other cusps have been added, as

many as six appearing in some primates. The human molar, therefore, is a reversion to the lemurine type. Brinton affirms that the study of these traits in racial anatomy has no definite result.

Two essays in the *Contemporary Review*, by Mr. Herbert Spencer, on the insufficiency of "natural selection," were the occasion of many papers by anthropologists representing a variety of points of view. Notable among these should be read Cattell on Survival of the Fittest and Sensation Areas.

Prof. Hartmann published the second part of his second volume on the anthropological material in the Royal University at Berlin (*Appendix to Arch. f. Anthrop.*, XXII, pt. 3). The classes treated are: Old Egyptian skulls; Guanches, of Teneriffe; Nigritians; modern Egyptians; Bantu, Kaffirs and Bechuana; Khoi-Khoi, or Hottentots; San, or Bushmen; Germans from the interior of Austria; Sloven; Finns.

Upon the question of the color-sense among aborigines the experiments of Blake and Franklin among American Indians are valuable. It has been frequently affirmed that Indians do not know colors by name, but Gatschet's researches contradict this. At Haskel Institute four hundred and eighteen Indians of different tribes were tested, and only three cases of color blindness found to exist—two for red and one for green. These were males and all full blooded. This ratio of seven-tenths of 1 per cent as compared with 5·36 per cent in Switzerland and 4·12 in Germany would seem to argue the diminution of the faculty of color in civilization. (*Science*, New York, June 2.) Dr. J. Ambialet has studied with great care the artificial deformation of the head called Toulousian and published his results in *L'anthropologie* (Paris, IV, 11–27.) The paper is illustrated with many cuts, which add greatly to the clearness of the text. The people of Toulouse bandage the heads of their babies, and that compels the brain to grow out in other lines. These Toulousians are naturally short-headed, but by the effects of the constrictions mentioned they come to be dolichocephalic or long-headed and the skulls to be elongated, oval, pitched up at the occiput, trapezoidal, bilobic, etc.

The disastrous decrease of population in France has given rise to a national association termed "Congrès de la repopulation de la France." This society held its session the current year in Paris, under the presidency of Dr. Gustav Lagneau. Questions discussed were, assistance to poor children; protection to women with child; modifications of fiscal laws looking to increase of population; change of laws respecting illegitimates, etc. Resolutions denouncing war and advocating disarmament were passed.

The Marquis de Nadaillac has published a short paper (*Science*, January 27) on the extremes of heat and cold endured by man. The following records in centigrade are quoted:—

English and Russian officers, Maruchak, Afghanistan, —20° C.
Prince Henry, Central Asia, —40° C.

Captain Back, Fort Reliance, Canada, —56° C.
Captain Dawson, Fort Rae, —67° C.
Abbe Petitot, Fort Good Hope, —35° to 42° C.
M. Martin, E. Siberia, —63° C.
Gen. Greely, Discovery Bay, —66° F.*
Gilder, Northeast Canada, —71° C.
Buveyvier, Tuare Country, +68° C.

A difference of nearly 250° F.

PHYSIOLOGICAL PSYCHOLOGY.

In the International Congress of Experimental Psychology, of 1892, reported in *Mind*, 1893, II, 42–53, is printed a paper by Prof. A. Bain, on the respective spheres and mutual helps of introspection and psychophysical experiment in psychology. The author still holds that introspection, or the self-consciousness of each individual working apart must still remain at the head of the resources for imparting to psychology a scientific character. A few of the researches where both methods are applicable are:

(1) The muscular mechanism, the primary instrument of our activities for all purposes whatever.

(2) The theory of the intellect as expressed by such terms as memory, retentiveness, association, reproduction, and the like.

(3) The momentary fluctuations of ideas in and out of consciousness. Many phrases have come into use in connection with it, such as "threshold" of consciousness, recency of impressions, area of consciousness, lapses of attention, etc.

(4) The determination of the condition of permanent association or enduring memory, as against temporary or so-called "cram."

Among the great issues now awaiting solution Prof. Bain places in the foreground plurality of simultaneous impressions in every one of the senses. Attached to it is the question of the operative power of impressions while momentarily standing aside from the conscious area. For these problems introspection needs to be helped out by experimentation, while the delicacy of tact in the self-conscious observer is also of the utmost importance. One of the most pregnant issues in the whole field of psychology is the swaying of the will by motives outside of pleasure and pain, otherwise called the "fixed idea."

Until there is a more general agreement than at present on the analysis of the fundamentals of the intellect, it is premature to recommend a searching investigation into the working of similarity in diversity, on which hangs the inventive powers of the mind, just as much as simple memory reposes the adhesion of conjunctions in time. For the present there is abundant scope for introspection in roaming over the accessible facts of psychical life. By the nature of the case the initiative in the more fruitful inquiries will be most frequently taken by introspection, which also by its powers of analysis will still open the path to the highest generalities of our science.

Prof. Sully published an appeal to parents relative to studying the child-mind, of which the following is a brief:

1. *Attention and observation.*—Early attention and interest (in looking, touching, etc.) and gradually widening observation. Exact as well as hasty observation.

2. *Memory.*—Earliest recognition of persons. What is remembered best. Out-of-the-way facts, insignificant details, etc. Strength of verbal memory, new words introduced into a familiar story, and the like.

3. *Imagination and fancy.*—Anthropomorphic fancy, child-myth, personifications of nature. How the unknown in space and time is filled. Child-lies. Imagination interfering with observation and producing "illusions of sense."

4. *Reasoning.*—First curiosity about the origin of things, himself, of the Deity, etc. Childish puzzles, things that seem strange and inspire thinking. Childish explanation. How it translates our explanations of things, puts its meaning into our words.

5. First use of articulate sounds, characteristic omissions, alterations and transpositions of sounds in repeating words. Order of acquiring sounds. Invention of new word-sounds. Original applications of common words.

6. *Pleasure and pain.*—First manifestation of pleasure and displeasure (smiling, frowning, etc.). Instinctive and acquired likes and dislikes. Favorite amusements.

7. *Fear.*—First manifestation of fear—of the dark, of animals, of big moving things. Are they due to instinct or to experience or suggestion?

8. *Self-feeling.*—Self-pity, self-caressing, vanity, jealousy, property in toys, etc.

9. *Sympathy, affection.*—Early feelings toward animals and human beings as bearing on the question of innate sympathy. Cruelty of children.

10. *Artistic taste.*—Special preferences for colors, forms, rhythms, melodies, etc. Ideas of prettiness, grandeur, etc. First signs of laughter, or of a sense of the comical or ludicrous.

11. *Moral and religious feeling.*—Earliest signs of respect for authority. First exercise of judicial function by the child in scolding or commanding others or himself. First conception of right and wrong. Illustrations of feelings of justice in little children, of moral sensibility and of callousness.

12. *Volition.*—Imitation of others in words, gestures, etc. Effect of other's verbal suggestion on childish action. Examples of self-will, of defiance of commands. Hesitation in acting and self-restraint.

13. *Artistic productions.*—Spontaneous dramatic invention (make-believe) in play. Original manual construction (building, etc.). Invention of stories. First drawing of animals, men, etc. (Preserve examples.) Noticeable grades of progress in these.

Prof. Scripture contributes sound advice to those who would take graduate instruction in psychology (*Science*, New York, July 28). The student must begin with knowing the methods of making experiments; this should be followed by careful work in the theory of measurements, treating of the probability integral, the mean variation, etc. One of the great differences between psychological and physical measurements is that the conditions can not be controlled as in physics; mean variations are thus greater and the deductions from the results not the same. Psychological experiments resemble those taken once on each of a number of persons. The study of the methods of statistics has also to be made for the sake of mental statistics. The making of measurements brings in the study of fundamental and derived units and the construction of apparatus. The subject's touch, sight, hearing, etc., require a knowledge of the physical processes used in stimulation.

Hearing lectures will never make a psychologist; the fundamental course for all special instruction is the laboratory work. The student must be trained by repeated exercises in making the measurements explained in the lectures, including exercises on touch, temperature, hearing, sight, in the graphic method, chronometry, dynamometry, audiometry, photometry, colorimetry, etc. This should be followed by work in the construction of apparatus, elements of mechanical drawing, use of tools.

Journals specially devoted to psychic studies are:

The American Journal of Psychology. Worcester, Mass., Vol. V in 1893.
The Philosophical Review. Vol. I, in 1893.
Révue des Sciences Psychologiques. Paris. Vol. IV.
Journal of Morphology. Vol. VIII in 1893-'94.
Revue Philosophique. 18me année in 1893.
Zeitschrift für Psychologie und Physiologie der Sinnesorgane. Bd. V in 1893.
Vierteljahrsschrift für wissenschaftliche Philosophie. Bd. XVII in 1893.
Philosophische Monatshefte. Bd. XXVIII in 1893.
Zeitschrift für Philosophie und Philosophische Kritik. Bd. CII in 1893.
Philosophische Studien. Vol. IX in 1893.
Mind. A quarterly Review. London, n. s. Vol. II in 1893.
Revue internationale de Sociologie. Vol. I in 1893.
Rivista internazionale di Scienze sociale e Discipline ausiliare. Vol. I in 1893.
Philosophisches Jahrbuch. Bd. V in 1893.
Rivista Italiana di Filosofia. Anno VIII in 1893.
Brain. London. Parts 61 and 62 in 1893.
Proceedings of the Society for Psychical Research. Vol. IX in 1893; also Journal.
Revue de Métaphysique et de la Morale. Première année in 1893.

THE RACES OF MEN.

In the United States the chief sources of publication on ethnological topics are: The reports and papers of the Peabody Museum, in Cambridge; the journals of the Hemenway Southwestern Expedition; the transactions of the American Philosophical Society; but, most extended of all, the reports and bulletins of the Bureau of Ethnology, and the publications of the Smithsonian Institution and of the National Museum.

Abroad the study is stimulated in a multitude of ways. The Anthropological Institute of Great Britain and Ireland is specially strong in this line of study through its colonial attachments. Besides this society, the Colonial Museum, the British Museum, the Royal Asiatic Society, flood the world with good literature, especially concerning the Eastern Hemisphere. Branches of these great societies are established in Bombay, Calcutta, Hongkong, Shanghai, Sydney, Wellington, publishing also literature on ethnology.

Interest in the study of ethnology is kept alive in France partly by bringing to the city of Paris families and groups of colonial natives. In the Palais des Arts liberaux, Champs de Mars, was opened in 1893 an exposition of colonial African ethnology. Besides one hundred and thirty Dahomoans, representatives of the Ogowé, Whydah, Godomé,

Cotonou, Porto Novo, Allada, Savi, and Abomey peoples, were exhibited in native dress and habitations, working at their national trades. The chief source of information is *L'Anthropologie*, Paris, in which excellent reviews of the literature of the subject will be found.

Every German city has an ethnographic museum. In Berlin, Dr. Bastian, with a competent force, has charge of the great Museum für Völkerkunde and in Dresden Dr. A. B. Meyer has his home. The *Zeitschrift für Ethnologie*, Berlin, is a kind of diary or merchant's blotter, giving information concerning ethnological material as it comes to hand, to be journalized and posted up later on. The publications of the Dresden Museum on the Melanesian islanders are works of great merit.

In Holland the *Internationales Archiv für Ethnologie* is published at great expense by J. D. E. Schmelz, with colored lithographic plates. The work of Italian ethnologists must not be overlooked, especially in Central Africa. The *Archivio per l' Antropologia di Firenze*, organ of the Società di Antropologia, is the medium of publication.

Interest in the study of Etruscan origins still continues. Apropos of Dr. Brinton's suggestion that this people are to be classed with the Libyans, Prof. Giuseppe Sergi, of Rome, announces in *Nuova Antologia*, September, 1893, that from the side of physical anthropology this is true. In this connection should be read Dr. Kleinschmidt's reference of the Etruscans to the Aryan stock, nearest to Lithuanian and Lettish and Gaetano Polari's comparison of the same language with the Basque.

Dr. Zograf has studied the people of Great and Little Russia. They are not homogeneous, but result from the mixing of Slavo-Lithuanians and Uralo-Altaic elements. The people of Little Russia differ slightly from province to province in costume and manners. The region of the steppes which extend between the Carpathian and the Don has been peopled by colonies from diverse sources, by Great and Little Russians, Bulgarians, Servians, Moldavians, and Germans. The Nogais Tartars are cantoned in the Crimea. (*L'Anthropologie*, Paris, IV, 228.)

Dr. Braislin has studied the human nasal canal as an ethnological characteristic with reference to the viability of the white and negro race in the same area. He thinks that the wider, shorter, and shallower canals in the negroes account for their being more subject to pulmonary diseases and that they present characteristics specially adapted for preparing the inspired air of a tropical climate for reception into the lung structures. (*Science*, New York, March 31.)

Dr. Felix von Luschan, of Berlin, finds in the modern Jews, descendants of three different races, the Hittites, the Aryan Amorites, and the Semitic nomads, who immigrated into Syria about the time of Abraham. (*Science*, New York, January 12.)

The Veddahs of Ceylon were the subject of an exhaustive study by the brothers Sarasin. The census of the island gives 2,760,000 persons.

Singhalese (+Rodyias, 2,000)	1,847,000
Tamils (430,000 sedentary)	687,000

Indo-Arab (Moormen, 168,000)	187,000
Eurasians	18,000
Malays	9,000
Afghans, Arabs, Bengalese	7,000
Europeans	5,000
Veddahs (males, 1,177; females, 1,051)	2,228

An excellent review of this work is in *Archiv f. Anthropologie* (XXII, 316–327).

The Khmers, of Cambodia, have been studied by Dr. Maurel, and the results of his investigations are made known in one of the *Mémoires de la Société d'Anthropologie de Paris.* They are the easternmost branch of the Aryan stock arriving from India with their native culture and have become mixed with various other strains.

The publishers of *L'Anthropologie* have brought together the papers of Dr. Eitel upon the Hak-ka (Paris, IV, 129–181), the general title of the Chinese inhabiting the province of Canton. These people have spread themselves throughout Indo-China. With diverse elements that are mutually antagonistic, they seem to be bound together by a common interest. The population of Canton is as mixed as was that of England after the Norman conquest. The Miao-tse aborigines have been corralled in the mountainous districts to the northwest by a migrating people, who came to occupy the entire province and who entitled themselves the Aborigines (Pun-ti). Later, these had to defend themselves successively against two other invaders of different race. These last are the Hak-ka and the Tchao-Tcheow or Hok-lo. The last named prefer the water and the Hak-ka the land. Both peoples came from the northwest, one following the waters, the other the mountains. The monograph of Dr. Eitel is devoted to the Hak-ka, their ethnography and history.

Dr. Michaut has published a work on the Aïnos. As was often pointed out, these people are neither Mongol nor Japanese, but approach astonishingly the Russian Moujik and are probably an aberrant branch of the white race. They are remarkably pure in blood, and may foreshadow the coming of the Russian to the Pacific coast to claim their own. The language is absolutely special, but approaches the Mantchoo in phrase and syntax. (*Bull. Soc. d'Anthrop. de Paris*, 4. s., IV, 259–263.)

The greatest interest now centers in the ethnology of northeastern Asia outside the question of the identity of the present peoples with those of America. The Kamchatkans, Ghiliaks, Koriaks, Yukaghirs, and others are supposed to be the remnants of the aborigines of northern Asia and even of the Japanese Isles. The studies of Schlegel in Chinese, of Morse in the shell heaps of Japan are thought to be confirmatory of this. The arts of these small people agree in many respects with those of the Hyperborean Americans.

New light is thrown upon the African pigmies by the researches of Stuhlmann, an associate of Emin Bey. In stature they average 1·25

meters. They are very prognathic and brachycephalic and the color is brown or reddish yellow rather than black. Stuhlmann looks upon the pigmies as relics of a peculiar variety of our species that once extended over Africa and parts of Asia. Dr. Brinton however, in a lecture before the Washington Anthropological Society affirmed that the size of these people had been brought about through degeneration.

Mr. G. F. Scott Elliot, at the end of his notes on native West African customs, has the good judgment to give a catalogue of the tribes on the upper Zambesi, with names, geographical locations, and definite position by latitude and longitude. (*J. Anthrop. Inst.*, XXIII, 85.)

Dr. Karl Sapper publishes in *Petermann's Mittheilungen* a short account of the ethnography of Guatemala. The languages at present spoken or formerly used are:

1. The Pipil of Salamá.
2. The Pipil of Comapa.
3. The Pupulca.
4. The Carib.
5. Sinca.
6. The language of Yupiltepec.
7. The Maya.
8. Language of the Chujes.
9. The Chorti.
10. Mame or Mam.
11. Aguacatec.
12. Jacalteca.
13. Ixil.
14. Quiché.
15. Cakchiquel.
16. Jutuhil.
17. Uspanteca.
18. Pokomam.
19. Pokomchi.
20. Kekchi.

The second part of the paper relates to culture, and especial attention is given to the varieties of habitations,* and an excellent map accompanies, showing in color the location and spread of each language.

The Tierra del Fuegians received more than their share of attention in a monograph published in the *Archiv für Anthropologie* (Braunschweig, XXII, 155–218, figs. and tables). These islanders are given under three stocks.

(1) Ona (Wua; Jacana-Kunny of Fitzroy; Aonik of Brinton) in the east.

(2) Jahgan (Jagan or Japoos or Tekenika of Fitz Roy) in the south.

(3) Alakaluf (Alekoolip) in the southwest.

In every kind of cranial measurement these peoples are compared with one another and with the rest of mankind. The author comes to the long deferred conclusion that the Fuegians resemble Europeans most and came from that continent.

The Polynesian Society of Wellington, New Zealand, takes up the problem of the Oceanic races with great vigor, publishing a quarterly journal. Necessarily the great majority of papers are in the graphic rather than in the logic stage, as should be. Papers of general value are: On Savage Island, E. Tregear and J. M. Ossmond: Asiatic origin of Oceanic numerals, E. Best: Asiatic gods in the Pacific, E. Tregear; Relationship of Malayan languages, T. L. Stevens, and many communications on the Maories.

* *Peterm. Mittheil.*, Gotha, 1893, XXXIX, 1–14.

The Solomon islanders are in the midst of a series of archipelagoes whose population is often called melanoid or negroid. The studies of Hagen lead to the conclusion that there is not here an unique type (*L'Anthropologie*, Paris, IV, 215). Emigrants from the west, Malays and Polynesians, or Malayo-Polynesians, according to the linguists, have continually arrived there, following the currents and the winds, and have profoundly modified the older elements, creating really a Melano-Polynesian type.

GLOSSOLOGY.

In the *American Anthropologist* (VI, 381–407) Messrs. Hewitt and Dorsey attack Duponceau's theory of polysynthesis in the Indian languages. Mr. Hewitt is a learned Iroquois, and Dr. Dorsey is as familiar with Siouan languages as with his own. The former says: "The materials of the language of the Iroquois consists of notional words—nouns, verbs, adjectives; representative words—prefixive and independent pronouns; relational words—adverbs, conjunctions, and suffixive prepositions; and derivative elements, formatives and flexions." The distinctive nature and characteristic functions of these elements can not be changed at will by any speaker. In the category of notional words noun stems may not indifferently assume the functions of verb stems or adjective stems. The compound stems of word sentences may become parts of speech when the linguistic sense has come to regard the separate meanings of the elements thus combined. This is *para-synthesis*. In the Iroquoian speech all the developments of the language expressed by the terms, word-sentence, stem-formation, and inflection are based primarily on the well-known principle of juxtaposition and a more or less intimate fusion of elements, but the living and traditional usage of the language has established the following morphothetic canons:

(1) The simple or compound stem of a notional word or of a word-sentence may not be employed isolatedly without a prefixed simple or complex personal pronoun or a gender sign or flexion.

(2) Only two notional stems may be combined in the same word-sentence, and they must be of the same part of speech.

(3) The stem of a verb or adjective may be combined with the stem of a noun, and the stem of the verb or adjective must be placed after and never before the noun stem.

(4) An adjective stem may not be combined with a verb stem, but it may unite with the formative auxiliary thä', to *cause* or *make*, and with the inchoative ç.

(5) A qualificative or other word or element may not be interposed between the two combined stems of notional words, nor between the simple or compound notional stem and its simple or complex pronominal prefix, derivative and formative change being effected only by prefixing

or suffixing suitable flexions and formatives to the forms fixed by the foregoing canons.

Dr. Washington Matthews, reviewing the new edition of the *Riggs Dakota dictionary*, published by the Smithsonian Institution as Vol. IV of Contributions to Knowledge, pays a just tribute to the original work and its author. Great and worthy praise is bestowed upon the Rev. J. Owen Dorsey for the editorial supervision of the new volume, and the reviewer says that the improvements are largely dialectic. This shows how thoroughly the pioneer members of the Dakota mission did their scholarly work (*Am. Anthrop.*, Wash., VI, 96).

The question of the phoneticism of the Maya is reviewed by Cyrus Thomas in the *American Anthropologist* (Washington, VI, 241–270), who says that their ideographic character is maintained by Förstemann, Schellhas, Seler, and Valentini; their phonetic character by Charency, de Rosny, and Thomas, and an intermediate ground is assumed by Brinton, who gives to them the name ikonomatic.

A substantial contribution to the extension of ethnology through linguistics has been made by Rev. J. Owen Dorsey in a paper before the Madison meeting of the American Association proving that the Biloxis, a tribe on the southern border of Louisiana, belong to the Siouan or Dakotan linguistic stock. This family is now traced along the western side of the Mississippi River from the gulf to its source, throughout the entire drainage of the Missouri and the Arkansas and along the eastern slopes of the Appalachians from Washington city to central South Carolina.

Upon the study of American native languages abroad, Dr. Brinton draws attention to a report on American linguistics made at a conference in Madrid by Don Francisco de Fernandez y Gonzalez and printed by the Athenæum. In the *Anales de la Universidad*, of Santiago, Chile, is a paper entitled, "La linguística Americana, su historia y su estado actual," by Diego Barros Arana and Rodolfo Lenz.

A valuable addition to the resources of Mexican archæology is Dr. Seler's publication with textual explanation of Humboldt's collection of maguey paintings. In the city of Mexico, in 1803, Humboldt purchased sixteen hieroglyphic paintings collected by Boturini Benaducci, 1740, confiscated by the Government and placed in the hand of Leon da Gama to study. In 1806 these paintings were presented to the Berlin Royal Library and there they remained until in 1888, they were exhibited to the Congress of Americanists. Photographic facsimiles were published by the Royal Library as a gift to the Columbus Centennial.

But the remainder of Boturini's collections were scattered and lost sight of nearly a hundred years, until M. Aubin, 1830–1840, with assiduous care gathered them and took them to Paris. Fifty years longer they were kept with miserly circumspection from inquisitive eyes until M. Eugene Goupil bought them and placed them in the hands of M. Boban to catalogue. Already a volume has appeared entitled,

Documents pour servir a l'Histoire du Mexique, published by Leroux. Dr. Brinton furnishes in *Science* (March 10) a good account of the material, and says that all that has been previously written about Mexico has no more importance than the histories of Egypt, composed before the decipherment of the hieroglyphics.

In *Science* Dr. Cresson shows the method pursued by him in his attempt to analyze the Maya hieratic and demotic script by the phonetic elements of which it is composed. The Maya graphic system seems to be based upon a primitive ideographism, the elements derived from natural and artificial motives. These symbols received phonetic meanings. This representation of ideas or words by pictures, whole or abbreviated, Dr. Brinton calls the iconomatic stage of writing. Both Mexican and Maya were of this character. The Maya especially had gotten beyond it toward the higher stage. (*Science*, New York, December 15.)

Canon Isaac Taylor, reviewing a paper of von der Gabelentz on the probable connection between Basque and Berber speech, says: "We may adhere to the old conclusion that in the more essential points the affinities of the Basque are with the languages of the Ural-Altaic class, which are totally different from the Berber languages, which belong rather to the Hamitic fam ily. (*Acad.*, 1893, July 29.)

Since the appearance of Horatio Hale's paper on the possibility of inventing language, much has been written on child language. Clark University, at Worcester, has taken up the matter seriously of making a collection of the secret langua ges of children, of which the old time "hog Latin" is only one example.

TECHNOLOGY.

The divisions of primitive technology, out of which all useful human enterprises spring, are the following:

(1) The study of materials, their qualities and geographical distribution.

(2) The study of the forces of nature, power of man, beast, wind, water, elasticity of rigid substances and gases, electricity,—as they have been subdued and put to work by man.

(3) Tools, utensils, apparatus, the study of their working parts, their manual and operative parts, their attachments and consequent machines.

(4) Mechanics, the gradual working out of the inclined plane, lever roller, wheel and axle, pully, screw, and the like, for the conversion of time, direction of motion, resistance, one into another.

(5) The processes of work, the manner in which the operations of an industry have been carried on from beginning to end.

(6) The products of the arts in their designs, structures, functions, and influence on the whole body of human industry.

The round through which all these activities go is:

(1) Exploitation of the earth for raw material in its three kingdoms; and in the case of plants and animals, increasing the supply through domestication and cultivation.

(2) The application of tools and power to these substances so as to convert them into forms to gratify human desire or to meet human needs.

(3) The transfer of the material in any stage of its manipulation from place to place, on men, beasts, wagons, ships or trains, called transportation and travel.

(4) The buying and selling of commodities involving weighing, measuring, and valuing, or weights, measures, and money, the development of the middle man, the wholesale merchant, the retail merchant, the broker, the banker, etc.

(5) The consumption of the ultimate product and all the utensils and customs involved therein.

Each one of these operations in its historic elaboration involves the growth of the areas involved from the smallest territory occupied by a self-supporting tribe to the occupation of the entire earth as a single-culture area. It also includes the differentiation of labor among men, giving to every man a greater diversity of thought and action in each operation, and requiring at the same time the cooperation of a greater number of men as specialists to accomplish the same kind of work. To unfold all arts of all peoples in all time and gather them into a single system of technic life is the purpose of technologic science.

The effect of the earth on arts is *techno-geography;* the effect of races on arts is ethno-technography, and from each point of view that gives a different motive to studying man, the arts of life are classified on different concepts.

Nowadays every trade has its journal, and the publishers never lose an opportunity to explain and illustrate the evolution of their craft. The *Journal of the Society of Arts*, London, is the first publication to consult upon this topic.

Mr. E. H. Man gives an account of the technique of the Nicobar pottery (*J. Anthrop. Inst.*, XXIII, 21–27). The manufacture is confined to one small island named Chorora, and the entire work of preparing the clay and molding and firing the pots has to devolve on the women of the community. It is related that a Chorora woman, while visiting another island, attempted to make a cooking pot, but she paid the penalty with her life. Clay at Chorora having been exhausted, material must be had from other islands, demanding a sea trip of a few miles. The duty of procuring the clay and the sale of the finished articles devolves on the men. (Compare Holmes and Cushing, 6 An. Rep. Bur. Ethnol.)

Having prepared a quantity of clay by freeing it from small stones and other extraneous matter, and having kneaded it with fine sand until of a proper consistency, the operator seated herself on the ground and placed before her a piece of board on which she laid a ring or hoop

about 8 inches in diameter made of cocoanut leaves neatly bound together. This served as a stand for a shallow dish, in which was placed a circular piece of plantain leaf to facilitate the handling of the clay and preventing its adhesion to the unsized platter. With one or more handfuls of clay, according to the size of the pot, the base of the utensil was roughly shaped on the dish; then rolls of clay of the required thickness and previously prepared were built up layer after layer until the proper dimensions had been attained; the operator, the while turning the pot round and round, shaping it with her eye and hand. The vessels are set aside on a raised platform to dry for one or two days, according to the size of the pot and the state of the weather. When dry it is taken from the platform, superfluous clay on the inside scraped off with a Cyrena shell, and the excess of material on the outside removed by means of a fine strip of bamboo moistened. The hands of the potter moistened are gently passed over the inner and outer surfaces of the vessel to smooth them. The rim is finished off with the bamboo strip. For firing a primitive kiln is prepared in some open space near the hut, and bits of broken pottery are stuck in the ground a few inches apart to serve as a stand. Under the pot a layer of fine wood ashes and a quantity of cocoanut shells and scraps of firewood are heaped up and a wheel-like object larger than the pot is laid on its upturned base; against this are laid branches and firewood, which are to be lighted outside the vessel but are not to come in contact with it. The fuel is kindled and the flame fanned, if necessary, by two or three women, who, armed with sticks in both hands, act as stokers until the vessel is baked. It is removed with the sticks and left to cool upon a bed of fine sand, where it receives the necessary black stripes. The painting is accomplished by means of strips of unripe cocoanut husk 1 to 2 inches broad, laid on the pot while hot. The stain produced by the acid juice turns black in a moment. To save her fingers from being burnt the artist keeps the pot in position by means of a cocoanut-shell cup. The entire surface is then rubbed with moist strips of husk to give a light copper color to the whole surface. Makers' marks are added and the whole is completed.

The study of maize is the study of a large number of American Indian tribes. Ethnologists will therefore be grateful to Dr. J. W. Harshberger for his monograph on the origin and distribution of maize in America. The origin of the plant is sought in the highlands of Mexico, south of the twenty-second degree of north latitude. From this source it got into the United States by two routes, through northern Mexico and through the West Indian Islands. It was carried to South America by the Isthmus of Panama, extending, according to Brinton, along the great Andean system until it reached the Gran Chaco, where we find the native tribes, no way related to the Kechuas of Peru, borrowing its name from these people. South American words for maize

extended all over the West Indian Islands, showing that it was introduced to this archipelago from the southern continent.

Even in our day the Mexicans excel in feather mosaics, some beautiful examples of which are to be seen at the National Museum. But in pre-Columbian times more attention still was paid to such matters. Of this we have evidence in the beautiful examples lately brought to light. Mrs. Nuttall, at the World's Congress of Archæology, presented colored sketches of a great number, and Dr. Seler resumed the subject. (*Ztschr. f. Ethnol.*, Berlin, XXV, 44.)

M. Adrien Mortillet, in a classification of weapons of offense, bases his subdivisions upon the relation of the action to the hand, (1) held in the hand, (2) working by means of something held in the hand, or (3) thrown from the hand. Each one of the classes of bruising, slashing, and piercing weapons may again be thus subdivided. The Africans have developed the slashing projectile in two forms, the bladed arrow and the thrown knife or trumbash. M. Dybowski read a paper before the Paris Anthropological Society upon the last-named weapon. (*Bull. Soc. d'Anthrop. de Paris*, 4. s., IV, 97–100.)

Mr. J. D. McGuire, in the *American Anthropologist* (Washington, VI, 307–320), attacks the division of the stone age into paleolithic and neolithic from a new point of view. Unwittingly archæologists have gotten into the habit of calling chipped stone by the former and battered and ground stone by the latter title. Mr. McGuire clearly shows that battering stone is easier and therefore may be older than the chipping art. He shows that among the best-known writers there is no unanimity of opinion as to the status of the chipped-stone age, and avers that the weight of authority is against the existence of any considerable period of time in which man lived either in Europe or America, when his only implements were those that were chipped.

The evidences of extensive prehistoric irrigation are found in Arizona. Mr. F. Webb Hodge brings them together in the *American Anthropologist* (Washington, VI, 323–330). In the valleys of the Salado and the Gila, in southern Arizona, the ancient inhabitants engaged in agriculture by artificial irrigation to a vast extent. The principal canals constructed and used by the ancient inhabitants of the Salado Valley controlled the irrigation of at least 250,000 acres. The outlines of at least 150 miles of ancient main irrigating ditches may be readily traced, some of which meander southward from the river a distance of 14 miles.

From many hundreds of scattered sources Dr. Max Bartels has gathered the literature of the world upon the history of medicine among primitive peoples. It is not generally noticed that savages have a practice of medicine and surgery, notwithstanding their theory refers every disease to spirit influences. Indeed, there are in most tribes, besides the medicine man, wise women and men who give themselves to the cure of disease by medicine and wounds by treatment. The

work of Bartels treats, first, of the medicine man and his diagnoses and then discusses separately: (1) The phenomena and means of sickness; (2) the physician and his social standing; (3) diagnosis and names of diseases; (4) medicines and their applications; (5) forms of medical prescription; (6) water cure, by bathing, sweating, and drinking; (7) massage as such and in sorcery; (8) diet and other hygienic measures; (9) the methods of sorcery in healing; (10) special diseases, eye, ear, epilepsy, etc.; (11) the prevention of diseases, epidemics; (12) surgery, small and gross. The indexes and bibliography of the work are most useful to further study.

Upon the question of the settlement of America the author of this summary at the World's Congress of Anthropology in Chicago took the ground that the peopling of the American Continent from Asia is the only hypothesis tenable upon present data. There never was known to history a day in which commerce was not going on. Asiatic species of animals have migrated in the present epoch. A series of land-locked seas lie on a great circle from the Indian Ocean to Vancouver Island. These seas abound in the best food products of the world. Winds are favorable, oceanic movements are favorable, climate is favorable.

It is easier now to follow the currents of the ocean and the trade winds than it is to oppose them. Indeed, one of the advanced movements of civilization was in so doing. But the first migrants did not venture into the great aerial and oceanic currents. They remained on the shallow and land-locked water, where the food was most abundant and the danger least. Migration could have derived much momentum from the *vis a tergo*, applied by hostile men or favoring winds and currents. But we must look for the strongest motive in the active desires for food, defense, shelter, adventure, etc.

ÆSTHOLOGY OR THE SCIENCE OF BEAUTY.

The arts of pleasure are now studied on the side of technical evolution or elaboration. The forms and colors of art objects are derived from natural objects or from other art objects of a simpler culture stage. The departures from the lines of nature are referred to the want of skill in the artist, the want of vision or imagination, and the technical limitations or least-resistance lines of the material.

As in the evolution of the industrial arts, the invention, the inventor, and the public want grow and are dwarfed co-ordinately, so in the fine arts. The best illustration of the union of minds in one complicated æsthetic effect the world has ever seen was the buildings of the Chicago Exposition. The union of the plans of a dozen geniuses of structure and decoration formed a kind of artist trust or combine, the last step in the synthesis of the beautiful.

The charm of this artistic climax was enhanced by the presence on the grounds and in the buildings of all forms of art—textile, fictile, coloring, graphic, glyphic, tonic, landscape, and architectural. These

represented the progress of taste—national taste, savage taste, barbaric taste, historic taste, woven together like a beautiful tapestry.

In a former summary was given the tabulated form of weapons and tools adopted by M. Adrién de Mortillet in his lectures before the Ecole d' Anthropologie. The course in 1893 was devoted to dress and adornment, their history and diversities, considered in relation to parts of the body. Adornment followed the parts of the body, as follows:

Jewelry of the head—crowns, diadems, and frontlets. Jewelry of the ears—drops, pendants, and studs. Nose jewels, inserted in the septum or alae. Labrets, pélélé, botoque, bezote, and labrets. Teeth jewelry. Neck jewelry, neck rings, collars, torques. Shoulder and breast jewelry, epaulets and gorgets. Waist decoration, bands flexible and rigid. Decoration of the lower part of the body. Arm jewels, armlets, bracelets. Finger jewelry. Leg decorations, leglets and anklets. Foot jewelry. Jewelry of the clothing. (*Rev. Mensuelle*, III, 96.)

No journal or magazine is devoted to this kind of study of comparative art and the natural history of art. The work of Henry Balfour on the evolution of decorative art and the papers of Holmes in the reports of the Bureau of Ethnology may be taken as text-books.

SOCIOLOGY.

The comparative history of society is nowadays studied in the following aspects:

(1) The family group, or really the groups of human beings that stand around the mother and child, their number and duration.

(2) The governmental group, involving the structure and actions of hordes, tribes, confederacies, states, nations, and international agreements.

(3) The industrial group, commonly called guilds, unions, boards of trade, chambers, for mutual offense and defense in business.

(4) Social groups, for mutual entertainment, help, culture, etc.

(5) Religious groups, studied in the comparative science of religions.

The United States in addition to its governmental assemblies undertakes the study of the combinations of men as laborers and as business men.

Every university has a school of political and social science, and in Philadelphia is published the journal devoted to that subject with extended bibliographers. The Johns Hopkins University school issues series of studies of great value. A section of the American Association is devoted to economics in the widest sense of the term. All periodicals are filled with sociology; it is the most attractive of all scientific hobbies.

MYTHOLOGY AND FOLK-LORE.

Prof. Caird defines religion to be "man's ultimate attitude toward the universe." But, in trying to arrange a number of objects in accord-

ance with this definition it would be necessary further to explain its verbal elements.*

Religion, as it enters the field of comparative or scientific study, is what men think concerning a spirit world and what they do in pursuance of such thinking. The thoughts of a spirit world involve the following questions:

(1) Its location and physiography, systems of cosmogony.

(2) Its peoples, their forms, origins, lives, thoughts, sayings, etc.

(3) Its government, including its entire social system.

(4) Its relation to this world.

The operative side of religion, or the cult, includes also

(1) The place of worship and its fittings in all their details.

(2) The organization of society on the basis of religion and the place of each individual in the system.

(3) The conduct in and with respect to the holy place, including prayer, sacrifice, fasting, incense, music, decorations, feasts, preaching.

(4) Piety or every-day conduct toward the gods, especially the conduct of the laity.

(5) Sacred books or what took their place in more primitive society. The Musée des Religions, or the Guimet Museum in Paris, publishes La Révue des Religions and special monographs.

For American religions study the works of Brinton, Boas, Dorsey, Powell.

At a meeting of the Anthropological Society of Washington the subject of breaking vases deposited with the dead was discussed. Mr. Cushing said that formerly the notion at the basis of the custom was to kill the vessel and send its spirit to dwell with the owner in the other world. In modern times the custom also was a precaution against grave robbers. Prof. N. G. Poletis, of the University of Athens, works out the study of breaking vessels as a funeral rite of modern Greece. Vessels either specially dedicated to the deceased or having been used at funeral rites are broken at the grave. Fragments of vases have been discovered on the Bathron, at the upper opening of tombs at Mycenæ; huge heaps of potsherds are found at old Alexandria, Greek, Egyptian, and Roman, belonging to various epochs. The present Greek custom is to break clay vessels upon the grave, and also as the remains pass out in front of the dead man's house. Sometimes the same thing goes on along the whole road following the funeral. While the priest pronounces the words: "Dust thou art and unto dust shalt thou return," he pours water upon the grave from a vessel specially brought for the purpose. This done the vessel is instantly broken while the priest flings with it upon the grave a handful of earth. (*J. Anthrop. Inst.*, XXIII, 28–41.)

In his course of lectures in the École d'Anthropologie, M. André

* Edward Caird. The evolution of religion. Gifford Lectures, 1890–'91 and 1891–'92. Glasgow, 1893, Maclehose, 2 vols., 400 and 334 pages.

Lefèvre chose for his theme: Beliefs of ancient Greece; the peoples and their gods. The order in which the argument proceeded was—

(1) Hellenic origins; (2) Animistic beliefs; (3) Cult of the procreative powers, fire and of heroes; (4) Divine personages: the Dodonean group, the air and the earth; (5) Primitive Asiatic influences, Phrygia, Phœnicia; (6) Formation and recension of the Iliad and the Odyssey; (7) The Achaians, the two unfound groups; (8) The gods of Homer: Olympus, Zeus; (9) The gods of Homer: Hera, Athena and Odysseus, Poseidon; (10) The solar group: Dorian Apollo, Hephaestos; (11) Life and death according to the Homeric Achæans (Patroclus); (12) The Homeric lower world; (13) Hesiod: The poet and his contemporaries and their conception of life; (14) Hesiod: the Theogony; (15) Hesiod: The Chronids, Titans, Tartarus, physical notions; (16) Hercules, the demigod; (17) Dyonyssos, Bassareus, Bagaios, Zagreus, Sachus; (18) Demeter and the mysteries; (19) Orphism; (20) Syncilitism and decadence.—(*Rev. Mens.*, Paris, III, 26).

The fifth annual meeting of the American Folklore Society was held in Montreal, September 13. The society was incorporated, and measures taken to publish special monographs. The papers by Heli Chatelain on the retarded development of African civilization, by W. W. Newell on the material and objects of folklore, and by Adolf Gerber on Brer Rabbit, a comparative study, were of especial value.

ARCHÆOLOGY.

Dr. Moriz Hoernes lays down with great care the fundamental principles of a system of study and instruction in prehistoric archæology, of which the following is the scheme:

A.—DEFINITION

1. The relation of prehistory to history and to the historical study of antiquities.
2. The place of prehistory in the syllabus of anthropology, its relation to physical anthropology and ethnology.

B.—ANALYSIS.

1. Propædeutics.
   a. History of the science.
   b. Study of resources.
      a. Literary sources, both direct and indirect.
      b. Monuments (attention, 1, to the topographic and, 2, museographic order, by means of examining localities and handling the objects). Classification of objects, both on the natural history and the archæological concept.
   c. Criticism and explanation.
2. Systematic representation.
   a. Fundamental factors: Culture areas and groups of mankind.
   b. Development factors: Invention, borrowing, remodeling, transmitting.
   c. Separate forms or classes: Language, religion, jurisprudence, the family, the state, the house, and the hearth; food, clothing, ornament, weapons, tools, industries, trade, navigation, art, etc.
3. Typological representation: Forms of dwelling places, industrial places, fortifications, religious inclosures, cemeteries, depots, also apparatus, with their function and development.

4 Historical representation.

a. Natural history: Origin of men, stocks, original home, dispersions, formation of races.

b. Culture history: Intellectual domination of men over animals, tertiary times, paleolithic and neolithic periods, bronze period; the orient, its peculiar archæology and the influence of its historic culture stages upon prehistoric Europe; first appearance of later peoples of Europe in their historic sequence.

The year 1893 marks an epoch in American archæology and divides students into two sharply separated schools. The older school believes in the existence of paleolithic man in the United States, the new school does not. In the presence of such sites as Trenton, the former discovers geological evidence of the very great antiquity of man in the occurrence of rudely chipped objects *in situ*, the other school says these objects are in the talus and have rolled down from the surface above. The old school says, but these pieces are very rude and have nacred surfaces. Men used very rude or paleolithic tools first, and after that came the finer-finished tools. The new school says these pieces are the rubbish, the rejected mass of stone knappers. They are quarry refuse, and not tools at all. Many hundreds of thousands of them have been picked up in the workshops of the modern Indians. Mr. William H. Holmes, of the Bureau of Ethnology, made most of the diggings by which this opinion is substantiated.

In a paper by Holmes on the distribution of stone implements in the tide water portions of Maryland and Virginia, the author has in view the whole history of each stone implement, from the source of the raw material to the finding of the specimen where it finally left the hand of the savage. He speaks of the origin and form of the stone, the processes of manufacture, the rejection at the source of the stone of all pieces tried and found wanting, the transportation, the caching or storing, the specialization of form in after work and the uses or functions. Four materials were used for chipped tools, quartzite bowlders, quartz pebbles, rhyolite quarried in the mass, jasper quarried in the mass. Of these the author says: "It is of the utmost importance, in taking up the stone implements of a region, that each material be traced to its source so that from this point of view a study can be made of the work of quarrying, shaping, transporting, and finishing." Holmes gives the following classes of implements, in the order of distance from the quarry, beginning with the heaviest:

1. Mortars, and many improvised tools.
2. Sharpened bowlders for rude mauls and axes.
3. Notched and sharpened bowlders for hafting.
4. Picks and chisels for soapstone and other quarries.
5. Net sinkers, carried along the streams.
6. Pestles, shaped by picking.
7. Hammer stones, the better the shape the further they were carried.
8. Soapstone vessels, often 10 miles from quarry.
9. Grooved axes, selts, scrapers, drills, knives, spear points, arrow points, pipes, ornaments.

The paper is clearly illustrated. (*Am. Anthrop.*, Washington, VI, 1–14.

The *Journal of Geology*, published in Chicago, No. 1, January–February, 1893, will have a department of archaeologic geology, under the direction of Prof. William H. Holmes. Already papers on archaeology have appeared.

Comparative study slowly unravels the tangle of American archaeology and ethnology. Dr. J. Walter Fewkes witnessed and became familiar with the snake dance of the Hopi (Moki) Indians, and in studying the old writers, Sahagun in particular, was struck with the wonderful similarity of the Mexican pictures to the real dances in Arizona. This, with the co-operation of Dr. Ed. Seler, Dr. Fewkes has worked out in the *American Anthropologist.* (Washington, VI, 285–306.)

American archaeology was greatly enriched by the publication of a folio volume on the ruins of Tiahuanuco in the highlands of ancient Peru. The work consists of two parts, the text and 42 photolithographic plates. By means of maps, illustrations in the text, ground plans and sketches, the authors have placed themselves entirely at the service of the student. This work is of the same excellent character as the Necropolis of Ancon, issued by Reiss and Stübel a few years since. The authors discuss the ethnic origin of the sculptures, the material, the dimensions of the blocks (weighing as much as 150 tons), the means of transport for many miles and across several inlets of Lake Titicaca; the skill in dressing, smoothing and polishing, and carving, with implements not much harder than the stone itself.

A great shock was given to European archaeology by attacks upon the age of the Canstatt and the Neanderthal skull. It is well known that Prof. De Quatrefages went so far as to claim a Canstatt and a Neanderthal race for early Europe. In the report of the German Anthropological Congress it was shown that the first-named skull was found associated with Roman pottery, and the last-named was picked up on the surface. At the same conference Prof. Virchow indorsed the opinion of Steenstrup that the evidence of contemporaneity of man and mammoth in Europe is not only inadequate, but for climatic and geologic reasons no such co-existence was possible.

Oscar Montelius began the publication of his great work, *La civilisation primitive en Italie depuis l'introduction du métal*, upon which he has labored for twenty years. It will be an album of 300 plates grand 4to, with more than 3,500 woodcuts and explanatory text. His volume upon the history of the influence of Orientalism upon Europe during the Stone Age, the Bronze Age, and the Iron Age till about 500 B. C. is his *Civilization of Sweden in Heathen Times* in new form, done into French by Salomon Reinach.

The number of *Nature* for August 10 contains the account of a suit for libel brought by H. Rassam against Dr. Budge of the British Museum growing out of assertions alleged to have been made by the

latter in connection with the former's disposal of certain finds in Assyria. The outcome was a judgment against Budge of £50, which his confreres paid, because they believed he was acting always in the interests of the museum. (*Nature*, London, 1893, XLVIII, 343.)

PHYSIOGRAPHY AND ANTHROPOLOGY.

All sciences are coming more and more to contribute to anthropology. The International Geographic Conference in Chicago furnished an example of this statement. Mr. Gardiner G. Hubbard selected as the topic of his presidential address, The relation of air and water to temperature and life. The following titles also show the current of thought:

The relation of geography to History. Francis W. Parker.

Norway and the Vikings. Capt. Magnus Andersen.

Geographic instruction in public schools. W. B. Powell.

The relation of geography to physiography in our educational system. T. C. Chamberlain.

Early voyages along the northwest coast of America. George Davidson.

In their responses to call, Gen. Eaton, Gen. Greely and Maj. Powell all dwelt upon this close bond between geography and history.

Dr. F. Schrader delivered a lecture before the École d'Anthropologie on the influence of terrestrial forms upon human development. In the order of sequence from the North the author distinguishes five zones:

(1) A boreal zone, quasi continuous and little varied.

(2) A north temperate zone, extended, much varied, presenting for the development of humanity the greatest possible number of conditions.

(3) A south temperate zone analogous but inferior to the last named. More fit to receive culture than to create it.

(4) An inter-tropical or equatorial zone, hot, rainy, with alternations of aridity and continuity of heat. Less diversified in its ensemble than the temperate zone.

(5) A frigid zone of the south, of no importance in the development of man. (*Rev. Mens.*, Paris, III, 206–219.)

The destruction of vast numbers of animals by the men of early times in the eastern continent created a gap in the evidence upon which the knowledge of very early migrations is to be based. M. Edward Dupont has brought together his studies upon the fauna and man of the quaternary epoch (*Bull. Soc. Belge de géol.*, 1892). Especially valuable is the paper on the study of man considered as a geological force. Species disappeared before the coming of man, doubtless. Quite as true is it that they were exterminated by man. But in the earliest times this destruction was feeble and the author inclines to the view that the quaternary fauna disappeared through natural causes.

In the *Journal of the Anthropological Society of Bombay** for 1893,

* Vol. III, pp. 9-21.

is a paper on the treatment of cattle diseases. The original work was scratched on the leaf of the Palmyra (*Borassus flabelliformis*). Their use of drugs, especially those derived from the vegetable kingdom, was by no means inconsiderable. Forty-eight different plants are named, and in the essay identified, making it a valuable contribution to knowledge.

NORTH AMERICAN BOWS, ARROWS, AND QUIVERS.

By Otis Tufton Mason.

"If the canopy of Heaven were a bow, and the earth were the *cord* thereof; and if calamities were the arrows, and mankind the marks for those arrows; and if Almighty God, the tremendous and the glorious, were the unerring archer, to whom could the sons of Adam flee for protection? The sons of Adam must flee unto the Lord."—*Timur's Institutes*, p. xlviii.

In no series of museum specimens is the natural history of human invention better exemplified than in the apparatus of war and the chase. The history of warfare especially involves the right understanding of two words—offense and defense. The perfecting of defensive apparatus has been stimulated by the perfecting of weapons of offense, and on the contrary the ingenuity of the human mind has been taxed to make the offensive implement of war more powerful than the defensive.* Protection of the body is secured by what is generally termed armor. The protection of the family, the tribe, the army corps, is achieved by fortification of some kind.

In the modern art of war this conflict of defense against offense reaches its climax in the built-up steel rifle-cannon and the nickel and steel Harveyized armor plating. One of the modern guns will send its shot quite through a plate 20 inches thick. Now the primitive form of this terrible projectile was the arrow, and of the steel plate the ancestor was the trifling hide and stick armor of savagery.

Offensive implements in all ages and stages of culture are for three purposes—to bruise, to slash, and to pierce the body of the victim.

Bruising weapons are found everywhere, but were highly developed in the Polynesian area, because there abundance of hard wood exists and little stone with conchoidal fracture for chipping.

Among the African savages, because they possess iron which may be worked from the ore, edge or slashing weapons have been especially elaborated.

Among the American aborigines, where obsidian, jasper in all its varieties, chert, quartz, and other siliceous stones abound, piercing weapons seem to have been the favorite class.

*These two subjects as developed by the American aborigines will be treated subsequently. Shields and armor will be described by Mr. Walter Hough.

However, each of the chief types of savagery possesses in some form the three great classes of bruising, slashing, and piercing weapons. For instance, the Polynesians had the club, the spear, and the shark's-teeth sword. The Africans fought with knobsticks, assegais, bows and arrows, and edge weapons in great variety. The Americans, especially the Mexicans, developed a sword with obsidian edge and the tomahawk.

The further subdivision of these three classes of weapons is based upon their manipulation. Every weapon and every tool consists of two parts—the working part and the manual or operative part,—that which wounds or kills and that by which it is held or worked. Indeed, the fact is sometimes overlooked that the manual or operative part of a tool or weapon has undergone greater changes in the course of history than the working part. The bow therefore must be studied quite as carefully as the arrow.

In the rudest form of tool or weapon a single piece of stone or wood serves both purposes, but even in this simple form one part fits the hand better and the other is more adapted to the work. A stone used for bruising generally has one end better fitted to the hand and the other shaped by nature to effect the purpose. The stick used as a spear, or a club, or a sword, even in savagery, has the differentiation of holding end and working end.

This study of the manual end of a weapon gives rise to the classification of Adrien de Mortillet into weapons held and used in the hand, weapons thrown from the hand, and weapons worked by some intermediary apparatus between the hand and the working part.

Ballistic weapons of America are bolas, throwing sticks or sling-boards with their varied darts, slings and stones, blow-tubes and darts, and bows and arrows. Some tribes are said to throw the tomahawk with good effect. Each of these involves mechanical principles worthy of the most careful study.

In this paper attention will be confined to the types of bows, arrows, and quivers of the North American aborigines, with incidental references to similar forms found elsewhere. It is true that the tribes included within this area developed the greatest variety of forms of primitive bows and arrows. The built up bows of Asia, studied and described by Mr. Balfour,* are of a higher order of invention and need only be mentioned.

Mexican bows, arrows, and shields have been carefully described by Mr. Adolf Bandelier. The South American area has been little investigated, but the North American Indian archery affords an excellent opportunity for the consideration of all the forces and devices which entered into human inventions as motives.

The geographic distribution of materials for weapons and of game

* Henry Balfour, *Jour. Anthrop. Inst.*, London, vol. XIX.

has given rise to an infinite variety of forms. The failure of certain kinds of trees in many places has put the bowyers to their wit's end in devising substitutes for producing the bow's elasticity. The exigencies of climate and the gloved hand modify the form of the arrow in some regions. The progress of culture, the demands of social customs, and skill of the manufacturer enter into the study of the bow and the arrow. In other words, in passing from the Mexican border northward to the limit of human habitation, one finds the rudest arrow and the rudest bow and the most elaborate arrow and bow ever seen among savages.

Again, in making this journey he will observe how quickly his passage between certain isotherms, forested regions, deserts, tallies with a sensitiveness of the bow or the arrow, which take on new forms at every degree of latitude or temperature.

Finally, if the student be observant, the arrow will write for him long chapters about the people, the fishes, birds, and beasts of the separate regions and their peculiar habits.

The following scheme of weapons devised by M. Adrien de Mortillet is modified to fit the North American Area.

A.—BRUISING AND MANGLING WEAPONS

1. *Held in the hand.*—Stones, clubs.
2. *At end of handle.*—Pogamoggans and casse têtes.
3. *Thrown from hand.*—Sling stones, rabbit sticks, bolas.

B.—SLASHING AND TEARING WEAPONS.

4. *Held in hand.*—Stone daggers and swords.
5. *At end of handle.*—Sioux war clubs, tomahawks.
6. *Thrown from hand.*—Little used.

C.—PIERCING WEAPONS.

7. *Held in hand.*—Bone and stone daggers, slave killers.
8. *At end of handle.*—Lances of all kinds.
9. *Projectiles.*—Arrows, harpoons, blow-tube darts.

Besides those thrown from the hand—stones, rabbit sticks, and bolas—there were four types of manual or operative apparatus used for propelling missile weapons by the North American aborigines,—the bow, the throwing-stick, the sling, and the blow-tube.

The throwing-stick existed throughout the Eskimo area, in southeastern Alaska, on the coast of California and in Mexico. It is not necessary here to more than mention its occurrence in South America and Australia. This weapon has been described by the author at length in the report of the Smithsonian Institution (1884), and this paper was the starting point of half a dozen by others which well-nigh exhausted that subject.

The sling is found on the California coast north of San Francisco.

The blow-tube existed only in those areas where the cane grew in

abundance, especially in the Southern States of the Union. One or two tribes of the Muskhogean stock and the Cherokees employ this weapon for killing birds in swampy places. The Choctaws about New Orleans make still a compound blow-tube by fastening four or five reeds together after the manner of the Pandean pipe. In Mexico and Central America this weapon was common. In tropical South America, however, much care was bestowed upon the manufacture of two varieties of Zarabatana constructed of two pieces of wood grooved and fitted together and the Pucuna made by inserting one tube inside of another and tamping the intervening places with wax.

From the inventor's point of view, the blow-tube with the dart, driven to the mark by the elasticity of the breath, should be the antecedent and parent of the gun, pistol, and cannon.* Historically the archer was the father of the cannonier. It is doubtful whether the inventors of gunpowder ever saw an American or Malayan blow-tube.

The universal projecting device of North America was the bow for propelling arrows and barbed harpoons. It is found in its simplest form in the south and east and becomes more complicated as we travel westward and northward. The following types are to be distinguished:

First. The plain or "self" bow, made of a single piece of hard, elastic wood, in each locality the best that could be found. (Plates LXI–LXIII.)

Second. The compound bow made of two or more pieces of wood, baleen, antler, horn or bone fastened together. (Plates LXII, LXIV, LXV.)

Third. The sinew-lined bow, consisting of a single piece of yew or other wood, on the back of which shredded sinew is plastered by means of glue. (Plates LXI–LXIII.)

Fourth. The sinew-corded bow used almost exclusively by the Eskimo. They are made from drift and other wood and backed with finely twisted or braided sinew cord and reinforced with wedges, splints, and bridges. (Plates LXV–LXXIII.)

Each one of these four types may be sub-divided according to the region or tribe. Every location furnishes a species of wood or material best suited for the bow-maker, and this has its effect upon the structure of the weapon. The game to be killed is another cause of variation. The tribal fashions, and material, and game, bring to pass a goodly number of special forms of bows which will now have to be studied in more detail, commencing at the south where the structure is simplest and proceeding to the north where it is most complex. Associated with each type and structure and region of the bow was its appropriate arrow. Nothing could be more intimate than this relationship. It might almost with safety be said that the arrows of each culture region could be shot with little effect from the bows of another region.

Again, excepting the little piercer at the end, which does the killing, the arrow shaft and feathers and nock really belong to the bow, that is, to the manual or operative part before mentioned.

* It is worthy of note, that *etymologically* "cannon," is a derivative from the Greek κάννα—a reed.

VOCABULARY OF ARCHERY.

ARCHER, old French *archier*, Latin *arcarius*, from arcus, a bow; one who shoots with a bow; whence archery, shooting with a bow.

ARM-GUARD. The Japanese, in releasing, revolve the bow in the left hand; a guard is worn on the outer side of the forearm to catch the blow of the string.

ARROW, a piercing, stunning, or cutting missile shot from a bow. The possible parts are the pile or head, barb-piece, foreshaft, shaft or stele, feathering, nock, and seizings.

ARROW CEMENT, substance used in fastening the arrow-head to the shaft. A few tribes use glue or cement in making the sinew-backed bow.

ARROWHEAD, the part of an arrow designed to produce a wound. The parts of the primitive stone arrow-head are the tip or apex, faces, sides or edges, base, shank or tang, and facettes.

ARROW STRAIGHTENER, a piece of bone, horn, wood, or ivory, with a perforation to serve as a wrench in straightening arrow-shafts, barbs, etc.

BACK (side), the part of the bow away from the archer.

BACKED. A bow is backed when along the outside are fastened strips of wood, bone, horn, rawhide, baleen, sinew, or cord to increase the elasticity.

BALDRIC, the strap supporting a quiver or sheath, being worn over one shoulder, across the breast, and under the opposite arm; generally much ornamented.

BARB-PIECE, the piece of ivory, etc., on some arrows attached to the true head, and having barbs on the sides. This should be carefully discriminated from the foreshaft, which has another function altogether.

BASE of an arrow-head, the portion which fits into the shaft.

BELLY (inside), the part of a bow toward the archer, usually rounded.

BOW, an elastic weapon for casting an arrow from a string. (*See* Self-bow, compound bow, backed bow, grafted bow, built-up bow.) It is the manual part of the weapon.

BOW ARM, the arm holding the bow.

BOW CASE, a long bag or case of wood, skin, leather, or cloth, in which the bow is kept when not in use. Same as quiver.

BOW STAVE, the bow in a rough state. Bow-staves were an important item of commerce prior to the use of gun-powder and every thrifty Indian kept several on hand to work on at his leisure.

BOW-SHOT, the distance to which an arrow flies from a bow.

BOWSTRING, the string used in discharging a bow. The substances used, the method of treatment, and of nocking are important to notice.

BOW WOOD, the substances used for bows, generally wood, but horn, antler, bone, and metal have been employed.

BOWYER, a maker of bows. In many tribes these were professional bowyers.

BRACER (wrist-guard), a contrivance for protecting the archer's wrist from being galled by his bow-string.

BRACING (stringing), bending the bow and putting the eye of the string over the upper nock preparatory to shooting. The different methods of bracing throughout the world form an interesting study.

BUILT-UP BOW, one made by glueing pieces of elastic wood and other substances together, as in Asiatic examples (H. Balfour, *Jour. Anthrop. Inst.* vol. xix.)

BUTTS, pyramidal banks of earth used formerly for targets.

BUTT-SHAFT, a blunt arrow for shooting at a butt, the ancient style of target.

CHIPPING HAMMER, called also hammer stone, a stone used for knocking off chips or spalls in making stone arrowheads. There are really two kinds of these hammers, the hammer stone and the chipping hammer.

COCK-FEATHER, that feather of an arrow which is uppermost when the bow is drawn.

COMPOUND BOW, made of two or more pieces of wood, bone, antler, horn, or whalebone lashed or riveted or spliced together.

EYE, the loop of a bowstring which passes over the upper nock in bracing.

FACES, the broad, flat portions of an arrowhead.

FACETTES, the little surfaces left by chipping out a stone arrowhead.

FEATHERING, the strips of feather at the butt of an arrow, including the method of seizing or fastening.

FLAKER, the pointed implement of bone, antler, etc., used for shaping flint arrowheads, spearheads, etc., by pressure.

FLETCHER, and arrow maker, akin to *flèche*.

FOOTING, a piece of wood inserted in the shaftment of an arrow at the nock.

FORESHAFT, a piece of hard wood, bone, ivory, antler, etc., at the front end of an arrow to give weight and to serve for the attachment of the head or movable barb.

GRAFTED BOW, a species of compound bow formed of two pieces joined together at the handle or grip.

GRIP, the part of a bow grasped in the hand. The same term should be applied to the corresponding part of swords, daggers, etc., where it is differentiated in any manner.

GUARD (wrist guard), a shield of leather or other substance fastened to the wrist of the left hand to prevent injury from the bowstring (see bracer).

HORNS, the ends of a bow called also ears.

LIMBS, the parts of a bow above and below the handle or grip.

NOCK, properly the notch in the horn of the bow, but applied also to the whole of that part on which the string is fastened. Upper nock, the one held upward in bracing; lower nock, the one on the ground in bracing; also the notched part in the end of an arrow.

NOCKING, placing the arrow on the string preparatory to shooting.

NOCKING POINT, that place on a bowstring where the nock of the arrow is to be fitted, often whipped with silk.

NOOSE, the end of a string which occupies the lower horn of a bow.

OVER ARROWS, those shot over the center of the mark and beyond the target.

OVERHAND, shooting overhand is to shoot at the mark over the bow hand, when the head of the arrow is drawn inside of the bow.

PACKING, of leather, fish skin, or other soft substance used in binding the nocks and the grip of bows.

PILE, the head of an archery arrow; any arrowhead may bear the same name, in which case we have a one-pile, two-pile, three-pile arrow, etc.

PITCHING TOOL, or knapping tool, a column of antler or other hard substance, used between the hammer and the core in knocking off flakes of stone.

QUIVER. A case for holding the weapons of the archer—bow, arrows, fire-bag, etc.

REINFORCEMENTS, splints of a rigid material build into a compound or sinew-backed bow.

RELEASE, letting go the bowstring in shooting.

Prof. E. S. Morse characterizes the various releases as follows:

1. Primary release, thumb and first joint of forefinger pinching the arrow nock.
2. Secondary, thumb and second joint of forefinger, middle finger also on string.
3. Tertiary, thumb, and three fingers on the string.
4. Mediterranean, fore and middle fingers on the string.
5. Mongolian, thumb on string, with or without thumb ring.

RETRIEVING ARROW, one with a barbed head designed for retrieving fish or burrowing game.

RIBAND, a term applied to the stripes painted on arrow shafts, generally around the shaftment. These ribands have been called clan marks, owner marks, game tallies, etc.

SEFIN. (*See* Thumb ring.)

SELF BOW (simple), made of a single piece of wood or other material.

SHAFT, anciently an arrow, but strictly the portion behind the head, and in a foreshafted arrow the lighter portion behind the foreshaft.

SHAFT GROOVES, furrow cuts along an arrow shaft from the head backward; they have been called blood grooves and lightning grooves, but these names are objectionable as involving theories of function little understood.

SHAFTMENT, the part of an arrow on which the feathering is laid.

SHANK, the part of an arrowhead corresponding to the tang of the sword blade.

SHORT ARROWS, those which fall short of the mark.

SIDES of an arrowhead, the sharpened portions between the apex and the base, also called the edges.

SINEW-BACKED BOW, one whose elasticity is increased by the use of sinew along the back, either in a cable, as among the Eskimo, or laid on solid by means of glue, as in the western United States. Wedges, bridges and splints are also used.

SLEIGHT, the facility with which an archer releases his bowstring.

SPALL, a large flake of stone knocked off in blocking out arrow heads.

STELE (stale, shaft), the wooden part of an arrow, an arrow without feather or head.

STRINGER, a maker of bowstrings.

TARGET, a disk of straw covered with canvas, on which are painted concentric rings, used in archery as a mark in lieu of the ancient butt.

THUMB RING, a ring worn on the thumb in archery by those peoples that use the Mongolian release; called sefin by the Persians.

TIP, a term applied to the sharp apex of an arrowhead.

TRAJECTORY, the curve which an arrow describes in space, may be flat, high, etc.

VENEER, a thin strip of tough, elastic substance, glued to the back of a bow.

WEIGHT of a bow, the number of pounds required to draw a bow until the arrow may stand between the string and the belly, ascertained by suspending the bow at its grip and drawing with a spring scale.

WHIPPING (seizing, serving), wrapping any part of a bow or arrow with cord or sinew regularly laid on.

WIDE ARROWS, those shot to the right or left of the mark.

Most of the words contained in this vocabulary stand for characteristics which are important in the study of bows and arrows according to natural history methods. By means of these terms any number of bows and arrows may be laid out so as to become types for all subsequent accessions and classifications. False information is thus eliminated, slowly, but the most scrupulous curator is not able to get rid of all that at once.

In all times the bow and the arrow have been the basis of much art and metaphor. Not only is this true in higher culture, as in the Bible, the Homeric poems, or the "arrow-head" writing of the Mesopotamians, but even among the North American Indians. The charming Ute ditty,

> The doughty ant marched over the hill
> With but one arrow in his quiver,

could easily be matched in other tongues. The Indians of the Southwest fasten an arrow dipped in blood on the bodies of their stone fetiches and call them the lightning. And Mr. Frank Cushing suggests that the positions of the elements in cuneiform writing are those of arrows dropped from the hand in divination.

THE BOW.*

In ancient times there was no other weapon into which a human being could throw so much of himself—his hands, his eyes, his whole mind, and body.† At any rate this is true of North America, where this arm was pre-eminent. In Polynesia and in Africa the case would be different. All of the early travellers in America speak of the sincere attachment of the warrior or the hunter to his artillery.

The noteworthy parts or characteristics of a bow are—

1. Back, or part of the bow away from the archer.
2. Belly, or part toward the archer.
3. Limbs, or parts above and below the grip. Also called arms.
4. Grip, or portion held in the hand.
5. Nocks, or ends upon which the bowstring is attached.
6. Horns, or parts projecting beyond the limbs, at the end are the nocks.
7. String, made of sinew, babíche or cord.
8. Seizing, application of string to prevent the splitting of the wood.
9. Backing, sinew or other substance laid on to increase the elasticity.
10. Wrist guard, any device to prevent the bow-string from wounding the wrist of the left hand.

Bows, as to structure, are—

1. Self bows, made of a single piece. Of these the horns may be separate.
2. Backed bows
    - with sinew
        - in a cable. Called sinew corded bows.
        - glued on. Sinew lined bow.
        - wrapped about. Seized bows.
    - with veneer — many kinds..
3. Compound.

Bows are to be studied also as to their materials, their shape, their strength, their history, and their tradition. (Plates LXI–XCV.)

In every Indian wigwam were kept bow-staves on hand in different stages of readiness for work. Indeed, it has been often averred that an Indian was always on the lookout for a good piece of wood or other raw material. This, thought he, will make me a good snow-show frame or bow or arrow and I will cut it down. These treasures were put into careful training at once, bent, straightened, steamed, scraped, shaped, whenever a leisure moment arrived. No thrifty Indian was ever caught without a stock of artillery stores.

Instances are on record where the wood for bows, the scions for arrows, the stones for heads, and even the plumage for the feathering were articles of commerce.

As a rule, however, the savage mind had as its problem, not that of the modern of ransacking the earth for materials and transferring them to artificial centers of consumption, but the development of the resources

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* Consult Henry Balfour, "The Structure and Affinity of the Composite Bow," *J. Anthrop Inst.*, Lond., XIX; John Murdoch, A study of the Eskimo bows in the U. S. National Museum, Smithson. Rep., 1884, pt. ii; D. N. Anuchin, Bows and Arrows, Trans. Tiflis Archæol. Congress, Moscow, 1887; Lane Fox, Catalogue.

† Burton would claim this honor for the sword.

of each culture area, to make the bow and the arrow that each region would best help him to create. His was an epoch of differentiation.

"The rule laid down by the Apaches for making their bows and arrows was the following says Bourke:

"The length of the bow or rather of the string should be eight times the span from thumb to little finger of the warrior using it.

"The curvature of the bow was determined almost entirely by individual strength or caprice.

"The arrow should equal in length the distance from the owner's armpit to the extremity of his thumb nail, measured on the inner side of his extended arm; the stem should project beyond the reed to a distance equal to the span covered by the thumb and index finger. This measurement included the barb when made of sheet iron. The iron barb itself should be as long as the thumb from the end to the largest joint.

"Torquemada says that the Chichimecs, among whom he includes the Apaches, made bows according to their stature, a very vague expression. (*Mon. Ind. lib.*, XXI, introduction.)

"Gomara says that the Indians of Florida traen arcos de doce palmas. (*Hist. de las Indias*, 181.)

"Landa describes the Indians of Yucatan as making bows and arrows in the manner of the Apaches; La largura del arco es siempre algo menos que el que lo trae." (See *Cosas de Yucatan*, *Brasseur de Bourbourg*, Paris, 1864.*)

Baegert says the bows of the Lower California Indians were more than six feet long, slightly curved, and made from the root of the wild willow. The modern cottonwood bow, from the same region, is a long, clumsy affair, very near to the most primitive types. (Plate LXI, fig. 1.) The bow-strings were said to be made of the intestines of beasts. The shafts of arrows were common reeds straightened in the fire, six spans long, feathered, fore-shafted with heavy wood, a span and a half long, with triangular flint point.† (Plate XLI, fig. 2.)

Coville says that the Panamint Indians of Death's Valley, California, make their bows from the desert juniper (*Juniperus californica utahensis*). The Indian prefers a piece of wood from the trunk or a large limb of a tree that has died and seasoned while standing. In these desert mountains moist rot of dead wood never occurs. The bow rarely exceeds three feet in length and is strengthened by gluing to the back a covering composed of strips of deer sinew laid on lengthwise. The string is of twisted sinew or cord made from twisted hemp.‡

These Panamint belong to the Shoshonean stock, spread out over the Great Interior Basin, and all the tribes use the sinew-lined bow, with transverse wrappings of shredded sinew. (Plate LXI, fig. 4.)

The bow of the Chemehuevis (Shoshonean) is characteristic of the stock to which they belong, being of hard wood common in the region, elegantly backed with sinew and bound with shredded sinew, orna-

* Capt. J. G. Bourke, letter.

† *Smithsonian Report*, 1863, p. 362.

‡ *Am. Anthrop.*, Washington, 1892, vol. V, p. 360.

mented also at the end by the skin or rattle of the rattlesnake.* The type belongs to the stock everywhere.

"The Apache bow was made always of the tough, elastic mountain mulberry, called par excellence, 'Iltin,' or bow wood. Occasionally the cedar was employed, but the bows of horn, such as were to be seen among the Crows and other tribes of the Yellowstone region, were not to be found among the Apaches and their neighbors of Arizona.

"The elasticity of the fiber was increased by liberal applications of bear, or deer fat and sinew was, on rare occasions, glued to the back for the same purpose.†

It is not probable that any southern tribes of the family, to which the Apache belong, ever dwelt east of the Rocky Mountains. The Athapascan sinew veneered bow is found strictly west of the Rockies, the slender variety in the Basin and British Columbia, the flat variety on the Pacific Slope. The Navajo also have adopted this type of sinew-lined bow.

The Cherokees lived in the Piedmont portion of the Appalachians in Carolina, Georgia, and Tennessee. The finest oak, ash, and hickory abounds in this region. These tribes used every variety of available elastic wood for bows, the toughness of which they improved by dipping them in bear's oil and warming them before the fire.‡ The Cherokees were Iroquoian and their bows may be taken as the counterpart of those made by the Six Nations. The Algonquin bows were similar.

The Pawnee warrior always preferred a bow of *bois d'arc*, and besides the one in actual use he would often have in his lodge a stick of the same material, which at his leisure he would be working into shape as a provision against possible exigency. Bows of this wood were rarely traded away. *Bois d'arc*, however, was to be obtained only in the South, and for the purpose of procuring it a sort of commerce was kept up with certain tribes living there.§

The Blackfeet made their bows of the Osage Orange, but they were compelled to procure it by trade from the tribes down on the Arkansas River.‖ The Blackfeet are Siouan in language and dwelt in the buffalo country in northwestern Dakota. They were in the same mode of life as the Pawnees, who dwelt farther south and are of the Caddoan stock. The whole length of the Missouri River was traversed in this Blackfeet commerce. (Plate LXXXIV, fig. 2.)

The Central Eskimo, about Hudson Bay, have two kinds of bows (pitique), a wooden one (Boas's figs. 438 and 439, p. 502), and another made of reindeer antlers (Boas's figs. 440 and 441, p. 503). Parry gives a very good description of the former (II, p. 510):

"One of the best of their bows of a single piece of fir, 4 feet 8 inches in length, flat on the inner side and rounded on the outer, being 5 inches in girth about the middle, where, however, it is strengthened on the

* Whipple, etc., Pac. R. R. Rep., vol. III, p. 32, pl. 41, bow and quiver.

† J. G. Bourke, letter. Also J. G. Morice, Trans. Can. Inst., IV, 58.

‡ Timberlake, quoted by Jones, So. Indians, p. 252.

§ The Pawnee Indians, J. B. Dunbar.

‖ Maximilian's Travels, p. 257.

concave side, when strung, by a piece of bone 10 inches long, firmly secured by treenails of the same material. At each end is a horn of bone, or sometimes of wood covered with leather, with a deep notch for the reception of the string. The only wood which they can procure not possessing sufficient elasticity combined with strength, they ingeniously remedy the defect by securing to the back of the bow, and to the horns at each end, a quantity of small lines, each composed of a plat or "sinnet" of three sinews. The number of lines thus reaching from end to end is generally about thirty; but, besides these, several others are fastened with hitches round the bow, in pairs, commencing 8 inches from one end, and again united at the same distance from the other, making the whole number of strings in the middle of the bow sometimes amount to sixty. These being put on with the bow somewhat bent the contrary way, produce a spring so strong as to require considerable force as well as knack in stringing it, and giving the requisite velocity to the arrow. The bow is completed by a woolding round the middle and a wedge or two here and there, driven in to tighten it.

The bow represented in Boas's fig. 439, p. 503, is from Cumberland Sound and resembles the Iglulik pattern. The fastening of the sinew lines is different and the piece of bone giving additional strength to the central part is wanting. In Cumberland Sound and farther south wooden bows each made of a single piece were not very rare; the wood necessary for their manufacture was found in abundance on Tudjan (Resolution Island), whence it was brought to the more northern districts.

The bows which are made of antler generally consist of three pieces, a stout central one beveled on both ends and two limb pieces riveted to it. The central part is either below or above the limbs, as represented in Boas's fig. 440, p. 503. These bows are strengthened by sinew cord in the same way as the wooden ones, and generally the joints are secured by strong strings wound around them. A remarkable bow made of antlers is represented in Boas's fig. 441, p. 503. The grip is not beveled, but cut off straight at the ends. The joint is effected by two additional pieces on each side, a short stout one outside, a long thin one inside. These are firmly tied together with sinews. The short piece prevents the bow from breaking apart, the long one gives a powerful spring. The specimen figured by Boas was brought home by Hall from the Sinimiut of Pelly Bay, and a similar one was brought by Collinson from Victoria Land and deposited in the British Museum. The strings are attached to these bows in the same way as to the wooden ones."* Plate LXIV, fig. 4; LXV, figs. 1, 2.

The compound Eskimo bow is found in a region where timber does not grow, where driftwood even does not come in such state as to be serviceable, and where whale, narwhal, caribou, and musk ox furnish

* *cf.* Franz Boas, The Central Eskimo, *Rep. Bur. Ethnol.*, vol. VI, pp. 502, 503.

ideal material for the purpose. Last of all came the whaler with plenty of hoop wood, and the ship's blacksmith. In the National Museum the material for the compound bow is baleen, antler, horn, ivory, and wood from whale ships. The grip is the foundation piece, round and rigid. The limbs are worked to shape, spliced on to the ends of the grip and seized in place by a wrapping of sinew yarn or cord or sinnet. The notches are cut on both sides of the nock, which is often pegged on to the end of the limb with treenails. The whole class of projecting weapons must be looked upon as a lesson in techno-geography and as a remarkable example of the power of human ingenuity to throw off all precedents and predilections under sufficient stress and resort to those new methods which nature declares to be the only thing to do.

As previously intimated every Indian boy learned to make a bow. Every Indian man had a certain amount of skill in the art, and when he scoured about the forests, the capabilities of trees for his purposes engaged his thoughts. He saved up good pieces for a rainy day and made the improvement of his artillery a pastime. When he became old, if the fortunes of his existence accorded him such a doubtful blessing, he kept his hold on his tribe by becoming a bowyer when he could no longer take the field. Since the substances used in making bows are of the region, techno-geography finds an excellent illustration in the study of the bows of North America, which may be on this basis thus divided:

(1) *The hard-wood, self-bow area.* It embraced all North America east of the Rocky Mountains and south of Hudson Bay. This area extends beyond the mountains along the southern border, and is invaded by the compound bow at its northeastern extremity. Indeed, in those regions where more highly differentiated forms prevailed, it constantly occurs as the fundamental pattern. (Plates LXI–LXIV, LXXX, LXXXI, LXXXIII–LXXXVI, LXXXIX.)

(2) *The compound-bow area.* By the compound bow is meant one in which the grip and the two wings are separate pieces, or one in which the cupid's bow is made up of as many bits of horn as are necessary. There are really two compound-bow areas, the northeast Eskimo and the Siouan. The former has been described by Boas.

The compound bows of the Sioux are made of buffalo and sheep horn and of the antler of the elk. Dr. Washington Matthews states that he has seen a bow made of a single piece of elk horn. All the examples examined by the writer are wrapped with flannel or buckskin so as to conceal every trace of the joints made by the union of the different parts. The compound bows of the Sioux are the most beautiful in shape of any among savage tribes and recall the outlines of the conventional form of artists. In both types the compound bow arose from a dearth of wood for making a self-bow. (Plates LXII, LXIV, LXV.)

The horn bow was not confined to the parts of America inhabited by the great ruminants. Pandarus' bow is thus described by Homer—

> 'Twas formed of horn, and smoothed with artful toil,
> A mountain goat designed the shining spoil,
> Who pierced long since, beneath his arrows bled,
> The stately quarry on the cliffs lay dead,
> And sixteen palms his brows large honors spread.
> The workmen joined and shaped the bended horns,
> And beaten gold each taper point adorns.

(Balfour in the work quoted has exhausted this theme.)

(3) *The sinew-lined bow area.*—By sinew-lined bow is meant one in which finely shredded sinew is mixed with glue and laid on so that it resembles bark. This area extends up and down the Sierras in the western United States and British Columbia, on both slopes, and reaches as far north as the headwaters of the Mackenzie. (Plate LXI.)

The occurrence of hard wood in the Great Interior Basin and of yew and other soft woods on the western slopes gives rise to the wide, thin bow in the latter, and the long, ovate, sectioned bow in the basin.

The Shoshonean or narrow bow occupies the interior basin, and is found also in the hands of Athapascans in Canada, and Apache, Navajo, and Pueblo tribes farther south. Its chief characteristic, in addition to the ovate section, is that in many examples, at intervals of a few inches, after the back was laid on, it was wrapped with narrow bands of sinew. These hold the backing to the wood and prevent splitting (Pl. LXI). This device seems necessary with these narrow examples. Scarcely one may be found an inch across the back, affording not enough sticking space for the glue. With the broad California bows it was different.

(4) *The sinew-corded bow area.*—Where the bow has a backing made up of a long string or braid of sinew, passing to and fro along the back. This has been carefully studied and described by Murdoch.*

He divides the bows into classes, and shows how each of these classes originated, partly by the resources and exigencies of the environment and partly through outside influences. There are practically four classes of this corded or laced pattern, to wit:

(*a*) *The Cumberland Gulf type.*—In these the sinew cord, or yarn, is made fast to one nock, and passed backward and forward along the back of the compound bow forty or fifty times. In addition to this, additional strength is given by half turns and short excursions to and fro on the back of the grip. Mr. Murdoch considers this the primitive type of the sinew-backed bow. (Plates LXIV, LXV.)

(*b*) *The South Alaskan type.*—The bow is of wood, broad, flat, and straight, but narrowed and thickened at the grip. The back is flat, and the belly often keeled, and frequently a stiffener of wood or ivory occurs under the sinew lining. There is a subtype of this bow from

* *Report of U. S. National Museum*, 1884, p. 307–316. Plates I–XII.

the Kuskoquim area, in which the ends bend backward abruptly, so as to lie along the string, as in the Tatar bow. In this type the strands of sinew cord lie parallel, pass entirely from end to end, and the last one is wrapped spirally around the rest. The whole of the broad part cf the limbs is often seized down with spaced spiral turns of the cord. Next to the Cumberland type this is simplest, and is only a slight departure from it. (Plates LXV–LXVII.)

(*c*) *The Arctic type.*—The bow is shorter and narrower, the ends are often bent as in the Tatar bow, and strips of sealskin are put under the backing. The cord is always braided sinew, passes from nock to nock, but is laid on in a much more complicated manner, and much more "incorporated with the bow." The whole process of laying on the backing is minutely described by Mr. Murdoch. (Plates LXVIII–LXX.)

(*d*) *The Western type.*—Bow broader and flatter than the last, but less contracted at the grip, either straight or Tatar shape. The backing is in three parts, none of which extend as far as the nocks. The first cable goes from end to end near the nocks; the second from elbow to elbow, say a foot from each nock; the third along the straight part of the back. The cables become practically one along the grip. The method of laying down and knotting this intricate lashing must be studied from the figures (Plates LXXI, LXXII,) so that in the Eskimo area we have: (1) The plain or self-bow, of one piece; (2) the compound bow, of whalebone, antler, bone, ivory or wood; (3) the compound and sinew-corded bow; (4) the single-cabled straight bow; (5) the single-cabled Tatar or three-curved bow; (6) the complex-cabled straight bow; (7) the complex-cabled Tatar bow; (8) the three-cabled straight bow; (9) the three-cabled Tatar bow.

The material of bows varies geographically. Beginning in the south the regions may be roughly marked off—

(1) Mexican border: Cottonwood, willow, mezquit, bois d'arc, juniper.

(2) Southern United States: Hickory, oak, ash, hornbeam, walnut.

(3) Northeastern United States: Hickory, oak, ash, walnut, hornbeam, sycamore, dogwood, and, indeed, any of the many species of hard wood.

(4) Mississippi Valley: Same as on the Atlantic slope.

(5) Plains: Bois d'arc coffee tree and ash, wood procured in commerce.

(6) Interior basin: Mezquit in the south, abundant woods in the north, hard and elastic; species not determined.

(7) California and Oregon: Evergreen woods, yew, spruce.

(8) Columbia River: Same as California.

(9) Southeastern Alaska: Willow, spruce.

(9) Western Canada: Birch, willow, maple, spruce, cedar.

(10) Eskimo: Driftwood and timber from whale ships and wrecks.

The bow-string among the North American tribes was made of the following:

(1) Strips of tough rawhide plain or twisted.

(2) String made of the best fibers of the country—hemp, agave, etc.

(3) The intestines of animals cut into strips and twisted.

(4) But most frequently of sinew.

The strip of gristle extending from the head along the back and serving to support the former, and those taken from the lower part of the legs of deer and other ruminants were selected. These were hung up to dry. For making bow-strings the gristle was shredded with the fingers in fibers as fine as silk in some tribes, but coarser in others. These fibers were twisted into yarn on the thigh by means of the palm of the hand, after the manner of the cobbler. For making the twine some tribes employed only the fingers. Taking two yarns by one end between the tips of the thumb and forefinger extended of the left hand, the twister seized one yarn with his right hand, gave it two or three twists and laid it down on the palm of the left where it was kept in place by the fingers. Seizing the other yarn he repeated the process, brought it over the first yarn, laid it on the palm, caught the other yarn with the fingers of the left and seized the yarn first twisted with his right hand, all without losing a half turn. The writer has seen this work done with great rapidity. New strands of shredded sinew or vegetable fiber may be introduced at any time.

Both in New Mexico and in Alaska the natives make twine by means of a twister that works after the fashion of the watchman's rattle. But this device may be an innovation. The string of the Cherokee bow is said to have been made of twisted bear's gut.* The same material is mentioned in other connections east of the Mississippi River. There is a faint suspicion that in some instances the narrator mistakes the sinew cord for gut strings.

The study of the knots of savages is yet incomplete. Again many bows are sent to museums without strings, or unstrung, or falsely strung. The lower end of a bow-string, technically called the noose, was fastened on by the "timber-hitch," two half turns or hitches. There is no "eye," so called, wrought on the string, but the bow is strung by making two or more half hitches around the notches at the upper end. Neither is there any nocking point seizing on the bow-string of any American tribe.

The ancient bowyers made these ends of their bows of horn and trimmed and polished them in great fashion. Many examples from the Malayan and the Papuan area have the extremities very daintily carved. But the American bow has nothing approaching this. In a few Oregon examples the sinew backing is at the extremities gathered up in a hornlike extremity and finished off with fur, beads, and the like.

*Jones, So. Indians, 252.

Otherwise the end of the bow stave is rounded, cut in on one side or on two for the bow-string.

It was not the custom to apply a "packing" or a woolding on the grip of bows. The eastern tribes did not. But the compound bow of the Sioux, the flat yew bows of the California tribes, and the ellipsoidal sinew-backed bow of the Shoshonean tribes, were so treated. In addition to this, in many cases, the bows were painted in several colors, geometric figures were marked on them, and additions of bead-work made them quite fine. This decoration of the bow occurs among west coast tribes that manifest extraordinary artistic tastes in baskets and other work.

The warrior and the hunter tended their bows with as much care as though they were children. Every time they were used they were careful to oil them in order to preserve their elasticity. The western Eskimo wound up his bow when he desired to use it, and was careful to unwind and straighten it as soon as the hunt was over. This winding was done by twisting the sinew cable along the back by means of ivory levers making only a half turn, and then sliding their whole length through the cable before repeating the process. The ordinary self-bow when not in use was straightened and pushed into the bow case. (Plate XCIII.)

The author can find little authentic information concerning the bracing of the bow by the North American Indians. Those that he has seen perform the operation followed the old English method, placing the bottom horn against the hollow of the left foot, holding the upper horn in the left hand, bending the bow with the left knee, and tying the bowstring with the right hand. There was usually no eye in the bowstring that slid down on the bow and pushed up into the nock in bracing.

Frequent reference is made to the bracer or wrist guard of the North Americans. In the far north the gloved hand and the long sleeve made such device almost unnecessary, but a few specimens of carved bone or ivory objects in collections from the hyperborean area bear that name. The Indian, par excellence, wore upon his left wrist a band of rawhide, from 2 to 3 inches wide, as a guard against the bowstring. Many of these come from the Southwest, where they are ornamented with silver and worn in ceremonies.

"Among the Yurok bows and arrows were made by old men skilled in the art."* As will be seen further on in studying the arrow, there was really no guild or craft of bowyers. In his childhood the Indian made the best bow he could. Whatever ingenuity he expended upon it yielded him an immediate patent. He not only had the exclusive use of it, but every improvement which he made upon it inured to his advantage at once in the form of sustenance, flattery, and substantial social reward.

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* Powers, *Cont. to N. A. Ethnol.*, vol. III, p. 152.

So far as known the savages of America were right-handed. But there is nothing in any bow from the northern portion of the continent to show this fact. Left-handed archery was certainly quite uncommon. In a large number of darting boards or throwing sticks, which under certain technical exigencies are used by the Eskimos in place of the bow, there are only two specimens that are left-handed. Among the women of the same areas, not one implement has been found fitting the left hand.

The conditions of sending an arrow into the vital part of any game are distance, wind, varying elasticity of the bow, varying weight of the arrow, proper shape of the weapon, penetrability of the game. Each one of these variables is rendered as constant as possible by the hunter, in skulking, getting to windward, using wood of the greatest strength for bows, and making one's own arrows. The intellectual stimulus in the creation and using of the bow and arrow was incalculable.

Oliver Marcy gives the following on arrow penetration:

"I have in my possession the sixth dorsal vertebra of a buffalo, the spine of which contains an iron arrow point. The arrow struck the spine about 2 inches above the center of the spinal canal, and penetrated the bone 0·82 of an inch. The bone at the point struck is 0·55 of an inch thick, and the point of the arrow protrudes beyond the bone 0·27 of an inch. The arrow was shot from the right side of the animal and the plane of the point was horizontal. The animal was mature and the bones well ossified. Though the vertebra has been much weathered, the epiphyses adhere closely. The animal was not as large as some individuals. The whole vertical length of the vertebra is 13 inches.

"The arrow must have penetrated several inches of flesh before striking the bone." *

He does not take into consideration also the thick hide and matted woolly hair, both especially thick at the point struck.

As it is customary in rating the stature of a people to disregard the giants and the dwarfs, so in rating the North American projectile we may as well omit the marvellous and exceptional successes in company with the egregious shortcomings in order to know the importance of the average. When these allowances are made, there is enough to show that for accurate and rapid and effectual shooting the bow and arrow in the hands of a skilled warrior or hunter were a creditable weapon. The distance at which an Indian bow will do execution has not been studied among the tribes. As previously said, the design of the hunter or the warrior was to get close up. In all the sham battles which the writer has witnessed from his boyhood, the warriors almost touched each other. The dexterity with which they parried and fenced with the arm shield and the bow and arrow was marvellous. The absence of noise, the invention of game drives, the universality of decoys, the hundreds of disguises, the efficient skulking, the imitations of the cries of animals, all point to the intention of getting within a distance of 20 yards or less.

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*Science, vol. VII, p. 528.

The South American weapon is half as long again and may do better farther off.

At the request of the author the president of the Washington Archery Club, Mr. Maxon, made experiments in the penetrating power of Indian arrows and the propulsive power of Indian bows. The result was that the self or plain bows are not equal to the best archery bows. But the sinew-backed bows of the Pacific coast were capable of as great execution as man is capable of making.*

"Constant practice," says Capt. John G. Bourke, "had made the Apaches dextrous in the use of the bow, arrow, and lance; their aim was excellent, and the range attained was perhaps as much as 150 yards. I am able from my own recollection to supply a number of illustrations of the great force with which the arrow was discharged, although a person observing for the first time an arrow coming toward him would be surprised at its apparent lethargy.

"In the summer of 1871 I was riding by the side of Gen. Crook on the summit of the elevated plateau known as the Mohollon Mountains, in Arizona. We were a short distance ahead of a large column of cavalry and our immediate party was quite small. We ran into an Apache ambuscade. A number of arrows were discharged, two of them piercing pine trees to a depth of at least 6 inches. On another occasion a pine door three-eighths of an inch thick was penetrated. In July, 1870, a friend of mine, M. T. Kennedy, was mortally wounded by an Apache arrow which pierced his chest. The autopsy disclosed the fact that the arrow had no head."

"Mackenzie speaks of having driven a headless arrow 1 inch into a pine log on the Columbia River in 1793. (See *Voyages*, London, 1800, p. 269.)

"Maltebrun speaks of the force with which the Apaches shot their arrows. 'At a distance of 300 paces they can pierce a man.' (*Univ. Geog.*, art. 'Mexico,' Eng. translation, Philadelphia, 1832, vol. III, lib. or cap. 85th, p. 293.) I doubt this very much, as in my own experience I have limited their range to 150 yards.

"Cabeza de Vaca seems to have been greatly impressed with the dexterity of the Indians seen along his route from Florida to the Pacific coast settlements. He tells us that with their arrows they could pierce through oaks as thick as a man's thigh; that the range of the arrow was 200 paces; that Spaniards had been transfixed by arrows notwithstanding that they wore good armor. (In *Ternaux*, vol. VII, p. 107.)

"Don Antonio Espejo also asserts that the wild tribes living in the drainage of the Rio Grande could pierce a coat of mail with their arrows. (*See* his 'Relacion,' in Hakluyt, vol. III, 460, p. 461, A. D. 1581.)

"Domenech says that the Indians have trials of skill with arrows and will often keep ten in the air at one time. (*Deserts*, vol. II, p. 198.) Refers

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* For the contest between bow and musket, in 1792, at Pacton Green, Cumberland, and also at Chalk Farm, at 100 yards, *see* Hansard, vol. IX, p. xiii.

to Apache arrows sunk up to the feathers in the giant cactus on the side of the Santa Catalina Canyon in Arizona, 1870."*

Marvellous stories are told of the precision with which the American Indian could shoot. Cockburn said that the Indians of Darien could strike down with arrows the smallest flying bird. By shooting upward they were said to cause an arrow to pin a bird feeding on the ground. Sticking a shaft in the ground, they would shoot upward and the descending arrow would split the one sticking in the ground.†

The use of the bow was a part of the education of a boy. Among the many hundreds in the National Museum a great number are marked "boy's bow." In handling them the student must often speculate on the deferred breakfast that hung on the action of these miniature implements. We are told also that boys were frequently called out to shoot for prizes. That was the predecessor of all manual training schools, wherein skill and support went hand in hand with the Indian lad. Indeed, their games and pastimes were spirited imitations of the successes of their elders.

The author is not able to obtain reliable information as to whether the American tribes shot always "overhand"—that is, over the bow hand, with the arrow drawn inside the bow. Dr. Shufeldt, in his practical experiments to ascertain the mode of arrow release among the Navajos, incidentally remarks that the arrow was on the left side of the bow and rested on the top of the hand. In many descriptions, however, the forefinger is described as surrounding the arrow shaft.

At present the bow and the arrow have well nigh disappeared from the face of the earth as an active weapon. Four hundred years ago it stood in the forefront, where it had remained during thousands of years. It might be properly questioned whether, in the long run, the arrow had not destroyed more human lives than the bullet. In Canada, and sparingly elsewhere, bow guns or rude arbalests are found in the hands of Indians, but they are without doubt introduced. The arrow, having reached its highest elaboration as such in America, was superseded by the musket of the Aryan race.

The Iroquois tribes were among the first to receive firearms from the early settlers. On this account they soon abandoned the bow and the arrow. Colden says that they had entirely laid them aside in his day (1727). This abandonment of the bow for the gun has been spoken of as showing the Iroquois to have been a progressive people. Certain it is that this prompt adoption of the firearm put this confederacy at once at the head of the eastern Indians and made them a terror to the Algonquian tribes.

The almost entire absence of noise in the movement of the arrow and the shooting of the bow is the greatest differentiation from the gun, which alarmed the whole earth, man and beast. It may be said that

* Capt. J. G. Bourke, letter.

† Hansard, p. 26.

the noise of the gun put the man or beast to be killed quite as much out of the reach of that weapon as the little alarm created by the archer had moved the victim away from his weapon.

THE ARROW.

> "The ancient arrow-maker
> Made his arrow-heads of sandstone,
> Arrow-heads of chalcedony,
> Arrow-heads of flint and jasper,
> Smooth and sharpened at the edges,
> Hard and polished, keen and costly."
>
> LONGFELLOW.

The continent of America furnishes excellent facilities for the study of the arrow. Every variety of climate, material, and land or water game are here, to create an indefinite diversity of structures.

In its simplest form, the arrow is a straight rod pointed at one end, perhaps in the fire, and notched at the other end for the bow-string. But such a missile would be of little worth; and so the arrow has undergone many modifications in answer to the demands of the hunter. The parts of a highly developed arrow are the following:

(1) The shaft; of which it is necessary to study the material, the technique, the form, the length, the grooves, and the ornamentations.

(2) The shaftment; which is that part of the shaft upon which the feather is fastened. This section of the arrow varies in length, in form, and greatly in ornamentation, because it is the part of the weapon upon which bands and other ornamental marks are usually placed.

(3) The feathering; or the strips of feather or other thin material laid on at the butt of the arrow to give it directness of flight. The study of this feature includes the method of seizing; the attaching to the shaftment; the position of the feather, whether flat or perpendicular to the shaft; the manner of trimming the plume; the line, whether straight or spiral, upon which each feather is laid, and the glue or cement.

(4) The nock; or the posterior end of the arrow, seized by the fingers in releasing. This is a very important feature in the study of this weapon. For instance, the Eskimo arrows have flat nocks, while all other arrows in the world seem to be more or less cylindrical or spherical. In some the form is top-shaped; in others, bulbous; in others, cylindrical; and in others, spreading, like the tail of a fish or swallow. In modern arrows a footing is added to the nock.

(5) The notch; or cut made at the end of the arrow to receive the bowstring. Each stock of aborigines has its own way of making this cut at the end of the arrow; and this characteristic, born of the material, though seemingly unimportant, is frequently helpful to the student in deciding upon the tribe to which the arrow belongs.

(6) The foreshaft; or that piece of hard wood or bone or ivory or antler laid into the anterior portion of the shaft and trimmed to a symmetrical shape. It serves the double purpose of making the front

of the arrow heavier than the rear, and also affords a better means of attaching arrow-heads or harpoon barbs of special form.

(7) The head; or that anterior part of an arrow which makes the wound or produces the result. Before contact with the white race, aborigines were wont to make their arrow-heads of stone, bone, wood, shell, and even of cold hammered metal. The study of the arrow-head involves the point or blade, the faces of the blade, the facettes and serrations and notches of the expanding blade, the butt or tang for attachment, the barbs, and sometimes the barb piece, which is an extra bit of bone or other substance fastened to the posterior end of the stone head to multiply the number of barbs. (Plate LV, figs. 2, 3.)

Now, each one of these parts may be varied in number, in form, in material, in artistic finish; or one or more may be wanting. It will be seen therefore at once what an excellent instrument the arrow may be for the study of the natural history of invention, how it has been influenced by climate and by material resources, how it has been modified for definite functions, and has developed complexity with age.

It will readily be seen from an examination of the foregoing analysis that the creation of an arrow involves a great many of our modern crafts. In every locality the arrow-maker has shown, first of all, a wonderful acquaintance with the materials at hand, as though he had searched all the resources of the mineral, vegetable, and animal world, and after studying all there was, had selected the best. We are not able now to discover that the savage could have found any better material within his own environment. For the selection and creation of the shaft there was demanded a knowledge of the best kind of woods, and the invention of knives, straightening apparatus, "sandpaper," dyeing apparatus, and glue or cement of some kind. In fastening the various parts of the arrow together sinew was employed. The savage stripped from the leg or the neck of one of the larger mammals a mass of sinew which he allowed to dry. It was then carefully pounded and shredded. When he was ready to use this material he placed several of the strips or fillets in his mouth until they became thoroughly soaked with saliva. Then, holding with his left hand the parts to be attached and one end of the sinew fillet, he held the other part of the sinew in his right hand and revolved the arrow shaft with the left, holding the parts still together until one or two turns were made. He could then use the fingers of his left hand in smoothing down the sinew and directing its course, while with the right he held the unwound portions tight and directed the sinew to its position. When the wrapping or seizing was nearly finished the loose end was carefully drawn under the last turn or two, pulled tight, and cut off, so that neither end was visible. The whole was carefully rubbed down and allowed to dry. The sinew in drying shrunk very much and bound the parts firmly together. (Plate I, fig. 6.)

The feathers of the arrow are usually taken from the wing or tail feathers of rapacious birds, though others are sometimes used. The

feather is carefully split from one end to the other, and the pith and unnecessary parts of the quill carefully removed, so as to leave the plume and only a strip of the midrib. In laying the feather upon the arrow-shaft differences of manipulation existed among the different tribes. In some of them the midrib was laid close to the shaftment and glued tight, while the ends were seized with sinew, and the plume was shorn either very close to the shaftment in a parallel line or into some other artistic form. Not only the knowledge of birds was necessary in the choice and the arrangement of the feather, but there was a great deal of mythology connected with the proper bird whose feathers should be placed upon the arrow and the position and seizings connected with the feathering. (Plates XL–LX.)

The manufacture of the head of the arrow and its various parts involves knowledge of bone, ivory, or horn, and also familiar acquaintance with stone and stone-working. Arrowheads differ from one another in material, in size, in form, and in methods of attachment. The savage arrow-maker was a mineralogist. He not only knew the qualities of rocks but also their best methods of working, as well as the best conditions in which they existed for his purposes in nature. In each country the material employed is in every case the best from that region. In a large collection from the United States arrow-heads have been made of every variety of quartz, chalcedony, agate, jasper, hornstone, chert, novaculite, slate, argillite, and obsidian. In rare cases even quartz crystal, carnelian, amethyst, and opal were used. In working these materials the savage inventor soon found that the physical properties and availability of the material changed by natural surroundings. He knew by experimentation that a stone lying in a brook yielded him better results than one exposed to the sun and the weather on the open fields, and that a bowlder buried in the damp earth where it has lain for many centuries gave him safer results with less work than the brook pebble, so that he not only became a critical expert in the qualities of materials, but also was led to become a quarryman in order to exploit the proper materials. It has been very well shown by Professor Holmes that many spots supposed to have been the refuse heaps of Indian camps for many years, are only the sites of of ancient stone quarries, and the pieces found buried in these heaps are the refuse of their manufacture. In places the necessary rock could not be found in bowlders either on the surface or in the streams or in the gravel beds, but the materials were part of ancient ledges under ground, as in Ohio, Arkansas, and other places. It was necessary there to remove the surface soil, to dig out great pits, and by means of sledges and fire and other means within the capabilities of this Indian workman, to detach cores and masses of material which could be subsequently worked up into arrow-heads and other implements. As soon as the arrow-maker had secured his stock he began to work it up into the shape desired, first, with a stone hammer, by

means of which he knocked off flakes or spalls of the proper size and shape. Sometimes he would introduce between his stone hammer and the block of material a "pitching tool" of antler or hard bone. As soon as the flake of proper dimensions was removed, the next thing with the artist was to bring this into proper form by means of the flaking tool or flaker. The method of dressing the chip of flint into shape varied from tribe to tribe; in some the pressure was downward; in others it was upward; and the method of holding the hand and doing the work will be described under the head of "arrow-makers' tools." Arrow-heads are frequently confounded with spear-heads and knife or dagger-blades. The smallest objects of this class are usually arrow-heads, and the size alone would decide in many cases, because, after reaching a certain weight, the blade would defeat its own purpose by being any larger. But there is no difference in shape between the arrow-head and the other objects mentioned. A great deal of attention has been paid to the forms of arrow-heads, but they may be reduced to a few simple classes, such as the leaf-shaped, either complete or truncated; the triangular, and the stemmed. Sub divisions of these classes have been formed by archeologists, but many of these are such as have resulted from the limitations of the material in the hand of the artist. He has simply made that particular form because the material would yield to that and no other. Prof. Thomas Wilson, in classifying the arrows in the National Museum, mentions those, first, with beveled edges, the bevel being in one direction; second, with serrated edges; third, with bifurcated stems; fourth, with long barbs at the ends; fifth, triangular in section; sixth, broadest at the cutting end; and, seventh, all polished arrows.

As will be seen in the general and special descriptions of arrows, other substances besides stone were used for the heads. In the north and among the Esquimauan stock, frequently bone, ivory, antler, horn, and wood are found taking the place of stone. In each case that material was selected which would bring about the best results. For instance, what is called the "rankling" arrow, for the destruction of the reindeer, has its head made from the leg bones of the deer, the barbs upon the side are very sharp, and the dowel, for the insertion into the shaft of the arrow, very small, so that when the animal is struck the head would easily come out of the shaft and at every movement of the victim be carried further in toward its vital parts. Coming southward along the Pacific Slope, slate replaces chipped stone, and for barbed arrows native copper, bone, and wood are used. A few arrows from this region have also heads of shell. Along the Rocky Mountain slopes, in the land of the buffalo, before the days of iron heads, bone was used quite as often as stone in the fabrication of arrow-heads. Very few specimens are preserved in our museums of arrows from the tribes of the Eastern States, but historians convince us they were not different from their Western relatives in the material and

form of their arrow-heads. Of the ancient inhabitants of this continent the perishable material of arrows constituting the shaft and other parts has rotted and left us naught but the stone heads. Even those of bone and wood and other material have passed away, so as to leave the impression that the Indians of this eastern region used only stone; but all authorities agree that other substances were employed quite as frequently as the last named.

There are as many ways of classifying arrows as there are parts of the arrow, and more, some important parts furnishing several classific concepts. These will be set down as they occur without regard to order, each time seeking to exhaust the arrow.

Unbarbed—Designed to be withdrawn from the wound.		
Barbed....	Retrieving..	Fishing.
		Hunting.
	Rankling ...	Hunting.
		War.
	Entangling.	

The concept here is especially the existence and function of the barb, rather than number and structure of parts.

	Simple, entire, monoxylic.	
Shaft....	Of two parts................	Shaft.
		Fore-shaft and point.
	Of three parts..............	Shaft.
		Loose-shaft.
		Fore-shaft and point.
	Also	Shaft.
		Fore-shaft and point.
		Nock-piece footing.

As to the feathering, arrows are (1) without feather; (2) two feathered; (3) three or more feathered; and, as to the attachments, (1) glued to the shaft; (2) fastened only at the ends; (3) with the quill inserted at its ends into the arrow shaft. The nock of American arrows are (1) flat as in the hyperborean zone; (2) bulbous or spread, as in Canada and North United States; (3) cylindrical, as in California and the southern tier of States. (Plates XL–LX.)

There are innumerable references to ancient arrow-makers among the North American Indians, but the probability is that the life history of the bowyer is repeated in that of the superannuated fletcher. First comes the boy struggling through his primitive institute of technology, then the warrior or hunter, skillful in making an arrow and in wearing it out. Last of all he takes the wings of Hermes from his feet and spends his closing years in making arrows for his sons.

There was, according to Chippewa tradition, a particular class of men among our Northern tribes, before the introduction of firearms, called makers of arrow-heads. The same is related by other Algonkians.* Longfellow's ancient arrow-maker will occur to every reader at once.

The operations of constructing one of the more elaborate American

* Schoolcraft, S. Rp., vol. III, p. 81.

arrows led a man into many trades—quarryman, stone-cutter, mineralogist, sinew-dresser, and wood-worker. In the far North he must be also worker in bone, ivory, and horn. As a rule, in all savagery, both with men and women, the user of an implement must be its manufacturer. Yet, the differentiation of trades is a necessary step in the progress of culture, and our Indians had taken it more than once.

The North American savages were excellent quarrymen. In every region they knew the very best kinds of siliceous stones, the very best places to find these stones, the natural conditions under which they were kept in the most fracturable state, the best way to break, flake, and chip each stone into the desired shape.* The Indian was also a good lapidary, as numerous sites examined by Holmes will attest.

Arrow-heads are found in immense numbers about the fields and along the banks of rivers in the United States. It would not be an error to say that they are numbered by millions. They occur in great abundance upon the sites of ancient camps, near shell-heaps, fishing grounds, and about the fields where used to wander the deer and other game sought by the Aborigines. This is evidence that the making of an arrow-head was an easy matter, while the shaft required much time and patience to finish.

It has been said that by means of the stone, the shape and artistic skill with which it is wrought, the edges, the tang, and the consequent attachment to the shaft, arrows differ from tribe to tribe and individual makers show certain idiosyncrasies in the same tribe. Chert, slate and ivory in Eskimo land, wood and bone along the volcanic portions of the Pacific Slope, in British Columbia and Alaska; the most beautiful heads in the world of obsidian and jasper series in Oregon and California, coarser stone in the East at once proclaim what kind of arrows this or that tribe used.

According to Holmes the stages in making an arrowhead are fracturing, chipping, flaking. Fracturing is done at the quarry or wherever the original stone is picked up. The simplest fashion is breaking one stone with another; but stone from a quarry works better than surface bowlders. When the workable stone was in masses the Indian had more convenient tools, stone hammers or sledges, picks of wood or antler, and even fire if he had need of it. The first operation is to break up the original bowlders or masses so as to get out of its interior spalls capable of being wrought into blades. Each kind of stone had its own best way of treatment, whether quartz, quartzite, rhyolite, chert, agate, jasper, chalcedony, obsidian, or what not. There did not exist in the United States so pliable a form of flint as that occurring in great abundance in western Europe. Obsidian and jasper gave the best results.

Chipping was also done with a hammer, but, this time, a pebble of hard stone, oblong, convenient for the thumb and two fingers, and

* See W. H. Holmes, *Am. Anthropologist*, vols. v., vi.; J. C. McGuire, *id.*, vol. v.; H. C. Mercer, *Pop. Sc. Month.*

somewhat bluntly pointed. The writer has often seen arrow-makers hold a spall of stone in the left hand between the thumb and closed fore finger, and by means of a dainty hammer stone knock off flakes with the greatest rapidity, barely touching the edge of the spall at each blow. Arrow-heads for common use may be finished by this means. (Plate I.)

The flaking of blades was done with a flaker. The simplest form of the flaker is a piece of bone from the leg of a deer, pointed at one end. The essential characteristics of the working end of this tool are that it be stout enough to stand any amount of pressure that a man can give, and that it be of such a texture that it will "take hold" of the stone. The outer side of antler, hard bones from the legs of ruminants, and even soft iron are excellent, but ivory or steel are not good materials for flakers. (Plate I.)

The Eskimo* make the best flakers, working the point from antler of the caribou and the handle from ivory, carving the latter to fit the hand and to give to the workman the best "purchase." The point is set in the end of the handle and firmly lashed in place by means of rawhide.

All tribes do not use the flaker similarly. If the reader will take a tooth-brush handle in his right hand and a chip of siliceous stone in the other, he may try the following methods:

(1) Lay the spall or chip on a table or bit of wood, holding it firmly in place with the left thumb and forefinger. Grasp the tooth-brush firmly in the right hand, with the thumb on the top. The handle will work better if it be sharpened like a husking peg. Press down the point near the edge of the spall firmly, and remove chips along the under side.

(2) Lay the chip on the palm of the left hand gloved, or upon a bit of rawhide, holding it in place with the fingers, but not the thumb. Press off flakes along the edge of the chip.

(3) Grasp the chip between the thumb and forefinger, so that its outer edge will lie along the ball of the thumb. Hold firmly with fingers and press off flakes toward the thumb.

In all cases the operator needs confidence and knack. Wonderful results are achieved by good workmen in such brittle material as bottle glass, obsidian, and the jaspers.

There are in Washington several men connected with the Bureau of Ethnology who are capable of producing the most beautiful arrow-heads from bits of obsidian or glass.

Within the past year or two a new light has been thrown upon the whole operation of arrow-head-making. Extensive ancient quarries have been opened in Washington City, Ohio, Pennsylvania, Minnesota, Arkansas, and the processes revealed. There were several steps followed certainly by the eastern fletcher.†

(1) The digging of moist stone from the quarry.

* Murdoch, IX, *An. Rep. Bur. Ethnol.*, pp. 288, 289.

† See Holmes, *Am. Anthropologist*, vols. V and VI.

(2) The making of blanks on the spot.

(3) The finishing by the processes named.

The arrow-maker among the Virginia Indians, for making his shafts, used a knife with a blade of beaver tooth set in a wooden handle. This served him for saw, knife, and chisel. John Smith tells us that he made the notch in his arrow-shaft by grating with this knife. For chipping his arrow-heads of stone he used "a little bone, which he ever weareth at his bracer, or any splint of a stone or glasse in the forme of a hart." The arrow-head was fastened to the shaft with deer sinew, held firm by means of a glue made of the tops of deer horns boiled to a jelly. This method is not unlike that of the Apache, Utes, and other tribes of the great interior basin.*

This is a charming connecting link between the prehistoric and the historic. The knife with a blade of beaver tooth may at this very day be seen in the hands of the Eskimos about the Yukon mouth. One could say that a grip or handle of wood or antler had a groove sunk into one end, the root of the tooth was laid in this, and the two lashed with wet rawhide. At present the Eskimos use their beaver-tooth knife to put a fine edge on their blades of steel. The front enamel of the tooth is so much harder than the rear that it makes a perfect chisel, and would act well for knife or saw. "The little bone that he weareth at his bracer" for flaking his arrow-heads one might see any day in the hands of a Ute warrior a few years ago, and Maj. Powell collected and deposited several in the National Museum. This is simply a little bit of the fibula of the deer. On the west coast and in Eskimo-land this tool has its grip and its working part distinct. Finally, in the administration of the sinew for seizing, and the glue for binding all tight, one had only to watch the Apache Indian described in this text.

The arrows (*qaqdjung*) of the central Eskimos are made of round pieces of wood, generally tapering a little toward the lower end, to which two feathers of an owl or some other bird are attached. The bone heads of these arrows are joined to the shaft, as represented in Boas's fig. 443, p. 504. The difference in the methods used by the Mackenzie and the central tribes in fastening the point to the shaft is very striking. The arrow tang of the former and of the western tribes is pointed and inserted in the shaft (Boas's fig. 444, p. 505), while that of the latter is always beveled and lashed to it (Boas's figs. 442 and 443, p. 504). The direction of the bevel is either parallel or vertical to the edge (*id.* fig. 445, p. 505). Other forms of arrows are shown in *id.* fig. 446, p. 506. A similar difference between the fastenings of the foreshaft to the spear handle exists in the two localities. Western tribes give its base the form of a wedge (*id.* fig. 447, p. 506), which is inserted in the shaft, while the central Eskimos use a mortise. (Plates LII–LX.)

Formerly slate heads were in general use (*id.* fig. 448, p. 506); now the heads are almost everywhere made of iron or tin, riveted or tied to the

* *Eng. Scholar's Library.* Capt. J. Smith's works, No. 16, p. 68.

point (*id.* fig. 446, p. 506). In ancient graves flint heads are frequently found, some of which are represented in *id.* fig. 449, p. 507. On Southampton Island stone heads are in use even at the present time. Fig. 423, p. 491, probably shows how they were attached to the shank.*

The Panamint arrows are made from the stems of the reed (*Phragmites vulgaris*) and from willow shoots. The shafts are about 3½ feet long. Nearly mature, but still green, reeds are cut, their leaves removed, and the stems dried and straightened in the hands before a fire. Use is also made of a small stone, across the face of which have been cut two grooves large enough to admit an arrow shaft. This stone is heated, and a portion of the crude arrow is laid in one of the grooves until it is hot. The cane is then straightened by holding it crosswise in the teeth and drawing the end downward. By repeating this process throughout the whole length of the shaft a marvelously straight arrow is produced. The head of the arrow is a pin of very hard wood taken from some species of greasewood (*Stripler*). It is about 5 inches long, and tapers evenly to a blunt point. The base of the head is inserted about three-fourths of an inch into the hollow of the reed, and rests against the uppermost joint. It is bound in place by a thin band of sinew. At each joint of the arrow shaft is burned a ring of diagonal lines. The base of the shaft is notched to receive the bowstring, and feathered with three half feathers, bound on with sinews and twisted so as to give to the arrow a rotary motion.† (Pl. XLI, fig. 1.)

"The Spokane Indians laid a piece of buckskin on the hand, and from a flint pressed off flakes with a piece of deer's horn." These Indians belong to the Salishan family, and it is easy by means of the old material in the Museum to rehabilitate this ancient arrowmaker of Washington State. His process of flaking is that marked 4 in Plate I. The material on which he worked was incomparable, and his handiwork now forms the treasures of the Museum.

"At the base of Mount Uncle Sam" says Dulog, "on the west of Clear Lake, California, there is a tract 2 or 3 miles in extent covered with fragments of obsidian.

"With material so plentiful, the surrounding Indians are careful to choose only those pieces best shaped by nature for their purpose; but at places distant from the source of supply, the obsidian, which is often brought in large blocks, is chipped off in flakes from around a central core by blows of a rock.

"The old expert put on his left hand a piece of buckskin, with a hole cut in it to let the thumb pass through, something like the 'palm' used by sailmakers. This was of course to protect his hand while at work. In his right hand he took a tool of bone ground down to a blunt point. These tools, made often from the leg bone of a deer, are assorted in sizes, large ones being used for coarse work and small ones for fine work.

"A piece of obsidian of the right size was held in the left hand, then the right thumb was pressed on the top of the stone, while the point of

* Franz Boas. *The Central Eskimo*, VI *Rep. Bur. Ethnol.*, pp. 504–508.

† Coville, *Am. Anthrop.*, 1892, vol. V, p. 360.

the bone was strongly pressed against the under edge of the proposed arrowhead, and a little splinter of obsidian worked off. The operation was similar to the opening of a can with one of the old-fashioned can openers that work without leverage. Oftentimes material is spoiled in the sharpening. Around deserted camps piles of rejected fragments are sometimes found, either broken in putting on the edge or not being near enough the desired shape to pay for working up.

"A good deal of the sharpener's work, too, consisted in freshening up the edges of points blunted by use.

"One arrow-head, weather-worn by exposure, was shown me, with a border of fresh fractures extending from one-eighth to one-fourth of an inch in from the edge, where the sharpener's tool had been.

"There results from this process a serrated edge, which in the best specimens is beautifully fine and regular, but in rougher tools is often coarse. The old workman was careful of his stock in trade, and rolled up the fruit of his industry in a piece of ragged blanket to prevent its being injured while in transit from place to place."*

In this charming bit of description the old man played the following rôles:

(1) Discriminating the best pieces of stone to work, mineralogist.

(2) Obsidian knapper, stone-breaker.

(3) Flaker, with deer-horn tool working on the palm.

(4) As retouching injured blades, repairer of arrow-heads.

(5) Preserver of forms, a kind of wild Vishnu, laying up against future work all his stock in trade.

There seems to be little modern testimony to the assertion that the savage had learned to bevel the sides of his arrow heads alternately, for the purpose of making his arrow revolve in the air. Mr. Cushing has shown that this alternate beveling of the edges was a natural result of holding the piece of stone in a certain way along the thumb during the operation of chipping.

Lieut. Ray was the first to actually send to the National Museum a bit of antler, 6 inches long and about three quarters of an inch in diameter, to be used like a stonecutter's punch or pitching tool or a smith's punch in knocking off chips in the process of arrow-making.† But there are constant references to this intermediary tool. The writer, who has experimented in most aborginal stone-working methods, has not attempted to use this apparatus in order to know its limits.

The substitution of hoop iron and other metal and glass for arrowheads was one of the first lessons of acculturation learned by the American tribes. No custom or fashion was violated by this; the shaft and feather, that is, the manual part of the arrow, and all social and mythic portions remained unchanged.‡ This is the universal law of transfer from lower to higher grades. It is for the reason that woman's arts merely take better tools to do the very same work that savage women are easier to elevate than men.

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* H. G. Dulog, in *Forest and Stream*.

† See *Smithsonian Report*, 1886.

‡ Cf. Timberlake, quoted by Jones, So. Indians, 251; Lawson, 252.

For straightening the shafts of arrows, and even the bone or ivory used for points, the aborigines employed a kind of wrench. In the south it was merely a convenient bit of wood, spindle-shaped, having a hole through the middle. The Utes used the end of the horn of the mountain sheep, perforated with holes of different sizes. The Plains Indians utilized the hard bones of the buffalo. The West Coast tribes made use of blocks of elk horn, and the Eskimo carved out of walrus ivory excellent tools for this purpose.* (Plate XXXIX.)

For grinding down and polishing arrow shafts the Indian had a special set of tools. There are in the U. S. National Museum from several localities small slabs of sandstone with a shallow groove running longitudinally in which the arrow shaft was laid and drawn back and forward. The leaves of grass containing siliceous matter served for the smoothing process. Finally, a smooth stone or bit of bone served to rub down the shaft and put on the finishing touches. The term "shaft grooves" is preferable for those straight or serpentine or zigzag furrows cut on an arrow shaft between the shaftment and the head or the foreshaft. They have been alleged to be symbolical of the lightning to invoke the spirit of destruction to dwell in the arrow. Others denominate them "blood-streaks," supposing they promote bleeding from a wound, so that the hunter could follow up his game by the trail of blood. The reed shafts never bear such streaks; the Eskimo do not make them, neither do the Northwest Coast Indians. Athapascan, Shoshonean, Siouan, Kaiowan tribes are especially given to this practice. The furrows do not always follow the same plan, and it would have been easy some years ago to work out series of patterns for these marks and determine their relation to tribes. They are in general: (1) straight and parallel; (2) wavy and sinuous; (3) zigzag, without design. (Pl. XLI, fig. 3.)

The same tribe used arrows of about one length and weight, as correct shooting, like good penmanship, is a balancing of a hundred sensibilities. Every good archer drew his bow to the arrow-head every shot, for near or for far. If one's bow be drawn always to arrow-head, and one's arrows be always of the same length, whether from his own quiver or from another's, the elements of variability are much reduced. It must be from some such cause that the arrows of each tribe agree so nearly in length. Indeed, since neighboring tribes shoot one another's arrows, there is undoubted inter-tribal agreement in length within limits. It is not here affirmed that the arrows of a tribe are exactly of a length. The variations are within certain narrow limits.

The author has measured a large number of quiver contents. The arrows of one quiver agree absolutely. The arrows of a tribe agree within a narrow margin. Often, especially in the buffalo region, there seemed to be a species of international agreement in the length of the arrow.

The foreshafted arrow finds its occasion first of all in the country of

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* Boas., VI, *An. Rep. Bur. Ethnol.*, Washington, 525.

the reed cane—that is, along the southern portion of the United States. It may then be traced through those portions of California where the rhus, elder, and other pithy twigs abound. In the Eskimo area it has a multitude of structures and functions.

The foreshaft in the South and Southwest is a slender bit of hard wood sharpened and let into the top of the shaft and having the arrow-head attached to the fore end. The reasons are two. A hollow reed or a very pithy twig affords a very poor attachment for the arrow-head; and, secondly, this slenderer, heavier rod aids the directness of the flight. Indeed, the very long reed arrows of the Apache and Mohave tribes have for that reason insignificant feathers.

In the Eskimo arrows the heavy foreshaft of bone or ivory serves another purpose. Bone being heavier than wood, when one of these arrows is shot at an object in the water and the head is detached, the arrow stands perpendicular, and is dragged along by the divided line, the feather bobbing about and enabling the hunter to follow up his game.

In the harpoon arrow and the harpoon, the foreshaft furnishes an excellent socket piece for the barbed head or the "loose-shaft". There is no doubt, also, that its much greater specific gravity assists in the direct or straight-forward motion of the weapon. Many of these missiles are discharged into the water, in which case the ivory foreshaft is of great assistance.

It is often said by frontiersmen that the Plains Indians had two ways of mounting an arrow-head with relation to the notch at the nock. If the plane of the arrow-head be horizontal when the arrow is in position for shooting—that is, at right angles to the notch, the missile is a war arrow, to go between the ribs of men. But if the plane of the head be vertical when the bow is drawn, the missile is a hunting arrow for passing between the ribs of buffalo and other mammals.*

"Dodge explains that the Comanches place the notch of the arrow in the same plane with the notch of the string so that it may surely pass between the ribs of the animal which are up and down; for the same reason, the blade of the war arrow is perpendicular to the notch, the ribs of the human enemy being horizontal. (*Wild Indians*, San Francisco, 1882, 419.)

Captain Bourke thinks this is a mistake. He says, "I have seen all kinds in the same quiver."

There is more authority and reason for the assertion that the barbed arrowheads among these same Indians were for war and the leaf-shaped and rhomboidal heads were for hunting, because they could be easily withdrawn from the wound and used again; but the Eskimo have a barbed arrow, with ivory or bone barb piece, fitted into the head of the shaft in the most temporary fashion, so that when shot into an animal the head remains, rankles, and works its way into the flesh. For the

*On the plane of the head *cf.* Hansard, 212.

same reason the foreshafted arrows of the South and Southwest are loosely put together. The coloring of the shaft of arrows is technically called the riband. The Eastern tribes, the Basin tribes, and the Eskimo paint their arrows very little. Not much stress could be laid on this characteristic except on the California and Oregon coast. Here the author finds the following to be true: The arrows in the same quiver have the same riband. The arrows in the same tribe have the same general type of riband, and the same colors occur in old arrows. From tribe to tribe there occur differences in riband, but they have not been studied out.

The selling of prepared paints and dyes to the Indians by traders has introduced inextricable confusion into this characteristic. The riband on the arrow is generally in the shaftment or that portion of the arrow covered by the feathering. These bands and stripes have been called clan marks, owner marks, tribal marks, and the like, but they are not decisive in such matters.

According to Mr. Hough "African arrow-heads and feathering are fastened on with grass, palm-leaf strips, and other vegetable fibers, and many are tanged or socketed, and are not lashed at all."* Papuan arrows are served with vegetal fiber, the Ainos use bark, and in South America many tribes lash with natural fibers.

Most tribes of North America do not use any cement in fastening the head upon the shaft. The shrinking of the sinew is quite sufficient to hold all snugly in place. But in the Southwest of the United States, the *Algarobia glandulosa*, the *Prosopis juliflora*, and the *Laria mexicana* yield excellent gum, which is used by the Shoshonean and Yuman tribes to attach the arrow-head, without the use of the sinew.† (Pl. III, fig. 2.) Pine tree pitch and animal glue are also used.

The feathering of an arrow is an interesting study from place to place. It is governed by a host of considerations. As to this characteristic, arrows may be unfeathered, two feathered, three feathered, many feathered. The feathers vary in length from those only an inch to others a foot long; in adhesion, from those attached only at their extremities, and lying close or standing off, to others glued hard and fast to the shaftment their entire length. In some tribes the strips of feather are laid flat along the shaftment, as among the Eskimo and the west coast tribes, but in the great majority the feathers radiate from the shaft. In some tribes the strips of feathering are without ornament, in others they are shorn along the margins to be straight, triangular, and notched and a bit of downy feather is left at the nock as a streamer. In this respect, when carefully cut, some of the west-coast arrows present a decidedly natty appearance.

On one occasion an Apache Indian came to the author's department of the National Museum and, at his request, placed the feathering and

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* *American Naturalist*, vol. IV, p. 61. † *Am. Naturalist*, 1878, p. 595.

head upon an arrow. The feathers were split carefully and any excessive pith or horny portion of the quill removed. The pieces to form the feathering were trimmed to the same length. The Indian next shredded some sinew, which had been sent to the Museum from Hupa Reservation in California, prepared by the relatives of the Apaches that had been separated from them for centuries. This he chewed until it was soft and pliant. He was now ready to lay on his feathers. They were placed on the shaftment, wrapped slightly at the ends with sinew to hold them in position until they could be adjusted to suit his rigorous taste, at equal distances apart and at the proper distance from the nock. Placing the shaft under his left arm and holding the soft sinew in his right arm, he revolved the arrow with the thumb and fingers of his left hand and guided the wrapping with his right hand. Here was a primitive machine, with shaft and two bearings, used for the purpose of winding evenly a thread upon a spool. The wrapping or "seizing" of an Indian arrow is a very pretty and uniform piece of work. Mr. Hough calls attention to the operation of this Apache fletcher and gives drawing.* Among the northwestern Eskimos it is common to neglect the seizing of sinew and to insert the ends of the quill portion of the feather into the soft wood by means of a pointed ivory implement. As mentioned, very many Eskimo arrows are found without feathers at all, the very heavy foreshaft or iron head carrying the arrow forward with sufficient accuracy. On the other hand, many of the barbed harpoons and bird tridents of the Eskimo are provided with feathers. In the feathering of an arrow one feather must be uppermost, called in archery the cock feather. In some beautiful specimens from Cooks Inlet and near by one feather is snow white. But the author has examined many hundreds of arrows without being able to detect that the arrow-maker had in mind to draw attention to any one of the feathers so as to create a true bottom and top to his missile. In the Eskimo two-feathered arrow there is, of course, always one feather on top and another under.

The number of feathers on a North American arrow is an exceedingly variable quantity. As a general rule the Eskimo have two and the Indians three. This will do pretty well as a rule, but many three-feathered and no-feathered arrows occur in Eskimo land, and among Indain tribes no-feather arrows are common. The function of the feather is to retard the rear end of the missile and cause the arrow to go straight. This object being capable of accomplishment in other ways the feather may be omitted.

The feathering of an arrow must be studied:

(1) The species of bird from which the feather is taken.

(2) The number of feathers, two, three, many.

(3) The shape and trimming of the feathers.

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* *American Anthropologist*, IV, 61.

(4) Method of attachment, by siezing, or gluing, and to each of these there are many varieties.

(5) The part of the feather attached to the shaftment, close glued, standing off, or seized all along by a spiral sinew thread. In many museum specimens the glue has disappeared and feathers appear standing off that ought to be close laid.

The feathers of arrows are usually laid on in a line with the shaft, but many examples have come to light in which the feathers have a spiral direction on the shaftment. On one occasion the writer saw an Apache Indian finish the feathering of an arrow by seizing the two ends of the feathering and giving them a twist, simply to make the feathers lie flat on the arrow shaft. This goes for what it may be worth in accounting for the spiral position of many feathers. It is inconceivable that any savage should grasp the problem of the rifle bullet and construct his missile accordingly.

Captain J. G. Bourke, U. S. A., furnishes the following: "The Apaches use three hawk feathers, arranged equidistant along the shaft in the direction of the longer axis, fastened with sinew.

"The Uabes on the Amazon use three feathers spirally. (Wallace, *Amazon*, London, 1853, 493.)

"The Pimas of the Gila have two feathers instead of three. (*Cremony*, 103.)

"Mackenzie states that the Hare Indians of British North America who are, like the Apaches, members of the great Tinneh family, use but two feathers. (*Voyages*, London, 1800, 46.)

"According to Morgan, the arrows of the Iroquois had but two feathers and ended at the power extremity in a twist. (*League of the Iroquois*, N. Y., 1851, 306.)

"The arrows of the Apache-Yumas are feathered spirally with three feathers making a quarter-turn around the shaft. (Corbusier, in *Amer. Antiquarian*, November, 1886.)

"Maximilian, Prince of Wied, speaks of the feathers of the Mandan arrows being tied on at both ends like those of the Brazilians; he also speaks of the spiral line, either carved or painted red, which runs along the greater number of arrows, and says that it represents the lightning. (London, 1843, 389.)

"The explanation I received was that the runnel permitted the escape of blood and reduced the chances of expelling the arrow or the shaft."*

The nock of the American arrow is far more important than that on the bow. A good classification may be based on this characteristic as pointed out long ago by this writer. The following classes are easily recognized:

(1) The flat nock, as in all Eskimo arrows and in very few others.

(2) The cylindrical nock, most noteworthy on all reed arrow shafts of the South and in those of the far Orient.

(3) The bulbous nock, exaggerated in size on the West Coast, by cutting away the cedar wood as much as it would permit, and then wrap-

*J. G. Bourke, letter.

ping the butt end of the arrow with a narrow riband of birch bark until it resembled a small Turk's head knot. The Plains Indians also created a bulbous nock by whittling away the arrow shaft a fourth of an inch above the end, leaving a cylinder for a finger grip.

(4) The swallow-tail nock, an exceedingly dainty form affording a wide open notch and flaring finger grip, without waste of material. (Examples in Plates XLIII–XLVII.)

Notches for the bow-string were either very shallow, angular gashes, U-shaped cuts with parallel sides or gracefully curved incisions resembling the horizontal portion of the Greek letter psi.

Combining the notch with the nock the student has a mark which is helpful in deciding the band or tribe. At any rate, American arrows differ in both.

There is another characteristic noticeable at this point, the distance of the nock from the feathering. In some tribes the latter crowds down over the nock. In other, more dainty specimens, the feathering is several inches away.

This special characteristic connects itself with Prof. Morse's most interesting study respecting "arrow release." It will be easily seen that the thin, flat nock of the Eskimo lends itself easiest to the second or the third class of Prof. Morse, while the bulbous nock and the flaring nock conform most easily to his first class, in which the thumb and first joint of the forefinger pinch the butt of the arrow. Coming south, into the reed arrow country, where the nock is cylindrical, the Tertiary release might be looked for.

Dr. Shufeldt describes the method of arrow-release among the Navajoes.*

"Having read, with great interest, Prof. Morse's pamphlet on arrow-release, it was with no little curiosity that I handed a bow and two or three arrows to an old gray-headed warrior present, and asked him, 'Draw—as if you were about to kill the worst enemy you had in the whole world.' The old fellow seized the bow and arrows, and immediately drew one of them to its very head. This is the position he stood in at the time: His left foot was slightly in advance of the right, the bow was firmly seized at its middle with the left hand, while it was held somewhat obliquely, the upper moiety inclining toward the right from the vertical line, and, of course, the lower limb having a corresponding inclination toward the left side. The two spare arrows were held with the bow in the left hand, being confined by the fingers against its right outer aspect. With the right hand he seized the proximal end of the arrow in the string, using the thumb and index finger, at a point fully an inch or more above the notch, and consequently including the feathers. The ring finger bore against the string below this seizure, and its pressure was re enforced by its being overlapped by the middle digit, the little finger being curled within the palm of the hand.

"This corresponded to Prof. Morse's secondary release as figured on page 8, of the above referred-to pamphlet, with the exception that the middle finger should overlap the annularis, and was not of itself used

* *Am. Nat.*, vol. XXI, p. 784.

to draw back the string. I noticed, too, that the arrow at its head was on the *left side* of the bow and simply rested on top of his clinched hand. This man wore, in common with all the others who used the bow, a stiff leather bracer, fastened by buckskin strings about his left wrist, the collar being about 2 inches deep, and this, in several others who stood near and who wore them, was ornamented with silver buttons. He drew the arrow back and forth three or four times without changing the position of his finger or hands, when I suddenly asked him to shoot as if he were going to kill a squirrel running up a tree. He smiled at this and simply drew the bow the *same way*. Upon further questioning him, he told me that the Navajoes rarely held their spare arrows in the bow hand, as he now had them, but carried a scabbard (quiver of buckskin) full, in front of them, from which they could be removed with great rapidity while firing; this he immediately demonstrated to me from one of the scabbards worn by an Indian there present."

In archery-arrows and in Asiatic examples a piece of hard wood is inserted at the nocking end of the arrow. But in American arrows the nock is always a part of the wood of the shaft. This piece, in technical language, is called the "footing," but it need not be here discussed.

The subject of poisoned arrows in North America is a vexed one. A very high authority has said that the thing was unknown. But I have the testimony of Bourke to the contrary. No one avers that these aborigines prepared a vegetable poison, like the curari. But the toxic effect of putrid flesh was known, whether or not bitten freely by rattlesnakes. Dr. W. J. Hoffman will bring together the evidence on this subject.*

Powiaken, a Salish chief, declared to Mrs. McBean that obsidian and glass points in arrows were poisonous (U. S. N. M. letter).

The Koniagas poisoned their arrow and lance points with a preparation of aconite, by drying and pulverizing the root, mixing the powder with water and, when it fermented, applying it to their weapons.

Bourke furnishes the following: "Selecting the roots of such plants as grow alone, these are dried and pounded or grated." (*Sauer, Billing's Ex.*, *178.*)

They made arrow points of copper, obtaining a supply from the Kenai of Copper River: and the wood was as finely finished as if turned in a lathe.

"Die Pfeilspitzen sind aus Eisen oder Kupfer ersteres erhalten sie von den Kenayern, letzteres von den Tutnen." (*Baer*, *Stat. u. Ethn.*, *118.*)

"De pedernal en forma de arpon, cortado contanta delicadeza como pudiera hacerlo el mas habil lapidario." (*Bodega y Quadra*, *Nar.*, *MS.*, *66.*)†

* For Southern Indians, see Jones, p. 248. † See Bancroft, Native Races, I., 79.

THE QUIVER.

The quiver is difficult to study, because collectors have paid little attention to it. Among all the Plains tribes they are objects of beauty, and have been gathered as bric-a brac, with little information of their whereabouts. (Pl. LXXVII–XCIV.) The same rules are to be observed in the study of the quiver that we apply to all other objects connected with aboriginal industries. The quiver is largely of the region. In the first place the material out of which each example is made must be furnished by nature; hence it is of sealskin in one place, of cedar wood in another, of soft pelt in another, and in the south land is frequently made of some kind of soft basketry. Again, the structure of the quiver must be adapted to its function, that is, to the bow and arrows to be carried; also to the exigencies of the weather and the surroundings The parts of a most elaborate quiver are:

(1) The bow case, a long, slender bag, into which the bow is thrust.

(2) The arrow case, a pocket in which the arrows are kept, points downward, as a rule.

(3) The stiffener, a rod of wood attached along the outside of the arrow case, to keep it rigid.

(4) Baldric, a band of buckskin, or in the finest examples, of elegant fur, lined and decorated with quill work, passing over the left shoulder, across the breast, and attached by its ends to the quiver. It is for carrying the quiver.

(5) Fire bag, a leather pouch in which the Indian hunter kept his flints, steel, spunk, awl, and other subsidiary apparatus needful on his journey. It was tied to the middle of the bow case or the stiffener. Among several of the mountain tribes the squaw lavished all her skill upon her husband's quiver. The costliest beaver, marten, otter, and mountain lion pelt was invoked. It was lined with soft buckskin, or in later times with red strouding. Beads of every imaginable color were worked upon the border of the arrow case and upon the lining of the long pendant therefrom. Strips of fur, daintily cut in fringes, were sewed about the bottom of the bow case, and every spot capable of rich decoration received it. Between this and the plain salmon-skin capsule, into which the Eskimo thrust his arrows, there are many gradations of quivers, as will appear in the treatment of the several tribes.

"The quiver of the Central Eskimo, says Boas, is made of seal-skin, the hair of which is removed. It comprises three divisions, a larger one containing the bow and a smaller one containing 4 or 6 arrows, the head directed toward the lower end of the case. When extracted from the quiver they are ready for use. Between the two compartments there is also a small pouch, in which tools and extra arrow-heads are carried. (Plate XCIII).

"When travelling the Eskimo carry the quiver by an ivory handle; when in use it is hung over the left shoulder. Boas's fig. 451, p. 508, represents quiver handles, the first being fashioned in imitation of an ermine." *

* F. Boas, *The Central Eskimo*, VI *Rep. Bur. Ethnol.*, p. 508.

"The quiver of the Blackfeet was made from the cougar skin and was frequently valued at one horse."*

Throughout the area of fur-bearing animals the pelt of any one of them of sufficient size served as a quiver or arrow bag. These are, for the most part, slovenly in appearance. But the Blackfeet and other Plains tribes formerly made up their bow cases and quivers from large skins. In later times leather and cow's hide with the hair on were substituted. The elaborate make-up was preserved.

"The Yurok quiver was made of the skin of the raccoon or marten turned wrongside out and suspended by a string. In the lower end moss was stuffed as a cushion for the arrow-heads.† The bow was stuffed into this bag with the arrows and the wonder is how a man could keep the bow from destroying the arrows. In traveling, however, the bow was held in the left hand.

NOTES ON THE BOWS, ARROWS, AND QUIVERS OF VARIOUS TRIBES.

Baegert says that the shafts of the Southern California arrows consist of reeds, which they straighten by the fire. They are above 6 spans long, and have, at the lower end, a notch to catch the string, and 3 or 4 feathers about a finger long, not much projecting, and let into slits made for that purpose. At the upper end of the shaft a pointed piece of heavy wood, a span and a half long, is inserted, bearing usually at its extremity a flint of a triangular shape, almost resembling a serpent's tongue and indented like the edge of a saw. The Californians carry their bows and arrows always with them, and as they commence at an early age to use these weapons many of them become skillful archers.‡ (Plate XCI, XCII.)

The arms of the Apaches according to Pike are the bow and arrow. Their bow forms two demicircles, with a shoulder in the middle; the back of it is entirely covered with sinews, which are laid on in so nice a manner by the use of some glutinous substance as to be almost imperceptible; this gives great elasticity to the weapon. Their arrow is more than the "cloth yard" of the English, being 3½ feet long, the upper part consisting of some light rush or cane, into which is inserted a shaft of about 1 foot made of some hard, seasoned light wood; the point is of iron, bone, or stone, and when the arrow enters the body, in attempting to extract it the shaft [foreshaft] comes out of its socket and the point remains in the wound. With this weapon they shoot with such force as to go through the body of a man at a distance of 100 yards.§

"The Apache arrow was composed of three distinct parts—the reed, the stem, and the barb; the last affixed to the stem, and the stem, of

* *Maximilian, Travels, etc.*, 257.

† Powers, *Cont. to N. A. Ethnol.*, vol. III, p. 48.

‡ Baegert, Jacob, *Aboriginal Inhabitants of Californian Peninsula, Sm. Rep.*, 1863, p. 362.

§ *Pike's Expedition*, Phila., 1810, 10, Appendix to Part III.

hard wood, inserted in the reed, and both held firmly in place by ligatures of sinew. The stem was made of a hard wood called kk-ing, and the reed in Apache 'klo-ka,' meaning 'arrow grass.' There is a great advantage in the use of this reed, because the arrow afterwards needs no straightening, whereas the arrows made by the Zuñis and others must be subjected to a special process to make them shoot true.

"The use of sinew for securing the barb to the stem was believed to be based upon the fact that after the arrow had entered the body the warm blood, flowing from the wound, would soften and loosen the sinew, disengage the barb, and increase the discomfort, pain, and danger to the victim.

"It may be of interest to students of linguistics to know that the Apache word for bullet, 'ka,' is really the word for arrow, and much as the word has survived the weapon itself has survived, because the cross section of a rifle bullet, taken along the greater axis, is all the same as the same section made on a double-tanged arrow."*

"In the *American Naturalist*, vol. XL, p. 264, Mr. Edwin A. Barber describes nine different kinds of arrow-heads—leaf-shaped, triangular, indented at base, stemmed, barbed, beveled, diamond-shaped, awl-shaped, shaped like a serpent's head.

"All the above forms may be found in use among the Apaches to-day. The same warrior may have in his quiver representatives of several types, sometimes serrated, sometimes non-serrated, but all deadly. Arrows intended simply for the killing of birds or small game were not always barbed, but were generally provided with a cross piece about 2 inches below the tip. [This same stop is found in Canada.]

"The arrow of the Apache sometimes terminates in a triangular piece of hard wood, which seems to be perfectly effective as a weapon. One set of these is now in my possession, made of Florida orange wood by Koth li, a Chiricahua prisoner confined at Fort Marion.

"Just such arrows were observed by Columbus upon first reaching this continent. 'They carry however in lieu of arms, canes dried in the sun, on the ends of which they fix heads of wood, dried and sharpened to a point.' (Letters of Columbus, Hakluyt Soc., London, 1847, vol. II, p. 6.)*

"Stone arrow-heads were made preferably of obsidian (dolguini), next of chalcedony, petrified wood, jasper, or other siliceous rock, lastly of fragments of beer bottles; but if pieces of hoop iron could be picked up they were always utilized.

"Arrows made out of domestic glass were described over a century ago by Lawson, in his account of the Carolina Indians. He mentions having seen in an Indian town, 'very long arrows headed with pieces of glass which they had broken from bottles.' (Quoted by Squier and Davis, Mounds of the Mississippi Valley, in *Smithsonian Contributions*, vol. VI, 213; but there the opinion is expressed that these may have been obsidian.)

"It may be well to remember that the Indians of the Southwest were perfectly familiar with obsidian, and that the Apache name for glass means obsidian. It may have been only a coincidence, but I do not at this moment remember any glass arrows that were not brown glass, the nearest approach in appearance to obsidian. I have seen the green arrows, but they were made of the semi-precious stone called *aqua marina*, found among the Navajoes.

"Lyon, quoted by Bancroft (*Nat. Races*, vol. I, p. 342), refers to an

* J. G. Bourke, letter.

Indian (tribe not given) who made him a glass arrow from a fragment of porter bottle at the third trial, after he had learned the grain of the glass.

"The process of manufacture was in each case the same, and consisted in chipping small fragments from the edges of suitable pieces of material, the chipping implement being a portion of hardened deer or elk horn held in the right hand, the siliceous stone being held in the left over a flap of buckskin to protect the fingers.

"I once made it my business to solve the problem how long it would take Apaches whose village had been captured and destroyed by troops to provide themselves anew with weapons which would render them a menace to the scattered settlements of the frontier. I singled out an Apache at random and stipulated that he should employ no tools of iron, but allowed him to gather from the ground such chips of chalcedony as he pleased.

"He made a number of barbs, the time as recorded in my note-books being five, six, seven, and eight minutes; an expert might have done even better than that.

"I can not understand what Powers meant when he said that a Pomo Indian will spend days and even weeks upon one piece, unless he is alluding to some one making a 'medicine bow and arrows for a special occasion'. (Bancroft, *Nat. Races*, vol. I, p. 342.)

"Gen. George Crook, who was a very close observer of the habits and customs of the wild tribes among whom he served, relates that the Indians of Oregon used obsidian and made the barbs with remarkable facility and rapidity, from fifty to sixty in an hour. (*Smithsonian Report*, 1871.) He also states that the Klamaths were making their arrows of broken junk bottles, the tool used, a knife in place of a horn, and a blanket instead of a buckskin.

[Captain Bourke is evidently thinking of the making of arrow heads. Every tribe of Indians spent days and even weeks upon arrow shafts and bows. As in the manufacture of pottery the operation can not be finished at a single sitting as has been shown previously.]

"The Hoopa Indian, who is a relative of the Apache, makes his arrows in much the same manner, but the obsidian or jasper head is untanged and lashed with sinew."*

"Catlin says that every Apache tribe has its factory in which arrow-heads are made, and in those only certain adepts are allowed to make them for the use of the tribe. Erratic bowlders of flint are collected (and sometimes brought an immense distance) and broken with a sort of sledge-hammer, made of a rounded pebble of hornstone, set in a twisted withe, holding the stone and forming a handle.

"The stone, at the indiscriminate blows of the sledge, is broken into a hundred pieces, and such flakes selected as, from the angles of their fracture and thickness, will answer as the basis of an arrow-head; and in the hands of the artisan they are shaped into the beautiful forms and proportions which they desire, and which are to be seen in most of our museums.

"The master workman, seated on the ground, lays one of these flakes on the palm of his left hand, holding it firmly down with two or more fingers of the same hand, and with his right hand, between the thumb and two forefingers, places his chisel (or punch) on the point that is to be broken off; and a co-operator (a striker) sitting in front of him, with

* Capt. J. G. Bourke, letter.

a mallet of very hard wood, strikes the chisel (or punch) on the upper end, flaking the flint off on the under side, below each projecting point that is struck. The flint is then turned and chipped in the same manner from the opposite side, and so turned and chipped until the required shape and dimensions are obtained, all the fractures being made on the palm of the hand.

"In selecting a flake for the arrow-head a nice judgment must be used or the attempt will fail; a flake with two opposite parallel or nearly parallel planes is found, and of the thickness required for the center of the arrow-point. The first chipping reaches near to the center of these planes, but without quite breaking it away, and each chipping is shorter and shorter, until the shape and the edge of the arrow-head are formed.

"The yielding elasticity of the palm of the hand enables the chip to come off without breaking the body of the flint, which would be the case if they were broken on a hard substance. These people have no metallic instruments to work with, and the instrument (punch) which they use I was told was a piece of bone; but on examining it I found it to be a substance much harder, made of the tooth (incisor) of the sperm whale, or sea lion, which are often stranded on the coast of the Pacific. This punch is about 6 or 7 inches in length and 1 inch in diameter, with one rounded side and two plane sides; therefore presenting one acute and two obtuse angles to suit the points to be broken.

"This operation is very curious, both the holder and the striker singing, and the strokes of the mallet given exactly in time with the music, and with a sharp and rebounding blow, in which, the Indians tell us, is the great medicine (or mystery of the operation).

"The bows also of this tribe, as well as the arrow-heads, are made with great skill, either of wood and covered on the back with sinew, or of bone, said to be brought from the sea-coast, and probably from the sperm whale. These weapons, much like those of the Sioux and Comanches, for use on horseback, are short, for convenience of handling, and of great power, generally of 2½ feet in length, and their mode of using them in war and the chase is not surpassed by any Indians on the continent."*

"The bows of the Beothucs are all of sycamore, which being very scarce in their country, and the only wood it produces that is fit for this use, becomes very valuable. Mr. Peyton informed Lloyd that their bows were roughly made of mountain ash or dogwood; they were formed by splitting the piece of wood selected for the purpose down the middle, the round side of which formed the back of the bow. The sticks are not chosen with any nicety, some of them being knotty and very rude in appearance, but they show a considerable amount of constructive skill. Except in the grasp the inside of them is cut flat, but so obliquely and with so much skill that the string will vibrate in a direction coinciding directly with the thicker edge of the bow. The bow is fully 5½ feet long. The string was made of deer's sinew.

"Beothuc arrows were made of pine (white) or sycamore, and were slender, light, and straight. The head was a two-edged lance about 6 inches long, made of iron taken from the traps, and other objects of that metal, which they had stolen from the furriers and fishermen.

"Cartwright says, in his journal of a residence in Labrador, that the head of the arrow was a barbed lance 6 inches long made out of an old

* George Catlin, *Last Rambles*, pp. 187 to 190, in *Smithsonian Report*, 1885, p. 743.

nail let into a cleft in the top of the shaft, and secured there by a thread of deer's sinew. The stock was about 3 feet in length. It was feathered with the 'gray goose wing.' They also use the feathers of the 'gripp,' or sea eagle, on their arrows."*

This testimony is of the same character as that relating to John Smith. The Beothucs did not belong to any of the great Indian families known, but were a stock apart. The rudeness of manufacture is also noticeable in contrast with those of the Eskimo.

"The weapons used in the Ioway tribe, and of which these people have brought many, are very similar to those used in most of the uncivilized tribes of North America, consisting of the bow and arrows, the lance and the javelin, war-clubs, knives, etc., and with these, as a protection in battle, a leathern shield, made of the hide of the buffalo bull, sufficiently thick and hard to arrest an arrow or to turn the blade of a lance."†

The Ioways belong to the Siouan stock and their arrows are a shaft, iron head, and three tolerably long feathers. The nock is either bulbous or flaring, affording a grip for the thumb and fore finger. The quiver is an elaborate affair. Indeed the quivers of the Siouan and other stocks preying upon the buffalo were the most complicated on the continent.

The Blackfeet do not make bows of the horn of the elk or of the mountain sheep. Their country does not produce any wood suitable for bows, and they obtain by barter the bow wood, or yellow wood (*Maclura aurantiaca*) from the river Arkansas. For their quivers they prefer the skin of the cougar (*Felis concolor*, Linn). The tail hangs down from the quiver, is trimmed with red cloth on the inner side, embroidered with white beads and ornamented at the end or elsewhere with strips of skin-like tassels.

"I saw few lances among the Blackfeet, but many war clubs which they have taken from the Flatheads. Many have thick leather shields painted green and red, and hung with feathers and other things."‡

All the Sioux tribes use a short arrow, with long shaftment bearing three eagle feathers. The shafts were marked with the lightning furrows, and streaked in different colors. The Sioux procured iron centuries ago and substituted it for the stone head. One of the rarest specimens in any museum is a Sioux arrow with a jasper point.

Mr. Dorsey says that the Omaha use the following as their arrow-measures: From the inner angle of the elbow to the tip of the middle finger, and thence over the back of the hand to the wrist bone.

"When in need of arrow points the Sioux would take his rawhide or buckskin sack or bag and go in search of the above-mentioned stones; when found would take another heavy stone, and by striking and breaking the stone, would gather the fragments that would serve for arrow or spear points. Those flakes which required less work in trimming or

* T. G. B. Lloyd, *J. Anthrop. Inst.*, vol. IV, p. 28.

† Catlin's Indian Gallery, *Smithsonian Report*, 1885, part II, p. 148.

‡ Consult Maximilian, *Trav.*, 1843, p. 258.

chipping would be placed in his sack, and when enough were collected he would take them to his lodge to fashion. Holding the arrow, spear, or knife piece in his hand, he would chip carefully with another flint or iron rock, or placing the sharp edge against the projecting piece or particle to be removed, being careful in only chipping or forcing off sufficient to make the stone in proper shape, with sharp edge and point. They made the grooves in war clubs, axes, hammers, or bone breakers by constant pecking.

"There was another kind of arrow point they made of which I never heard before, and that was out of the front part of the foreleg of an elk, between fetlock and knee joint. They would take that bone and break it, and slivers that would answer were made into arrow points by grinding them on a stone. They make a good arrow point, but not so strong as the flint points.

"The stone arrow points were each separately bound with sinews to protect them from breaking even in the quiver, and the arrows were unwrapped before starting after a herd of buffalo."*

The unwrapping of the sinew before shooting is quite new testimony, but Mr. Allen has lived on the frontier many years in Montana.

"Among the plains Indians," says Dodge "a good bow takes a long time and much labor in its construction. The best wood is the osage orange ('*bois d'arc*' of the old French trappers, corrupted into 'bow dark' by plains Americans). This wood grows in comparatively a limited area of country, and long journeys are sometimes made to obtain it. Only the best are selected, straight, and as free as possible from knots. The seasoning process is slow and very thorough. A little cutting, shaping, and scraping with knife or piece of glass, then a hard rubbing wi h buffalo fat or brains, and the stick is put aside in a warm place, to be worked at again in a few days or weeks. A good bow with fair usage will last many years, but it is liable to be broken at any time by accident. Each warrior, therefore, possesses several sticks of bow wood in various stages of completion.

"The strings are formed of closely-twisted fibers of the sinews of animals. These sinews are cut out their full length. Each is then subdivided longitudinally into strings, and these picked and re-picked into fibers as fine as hair and as long as possible. With the rude means at their disposal it requires no little skill so to put and twist these fibers together as to form a string perfectly round and of precisely the same size and tension from end to end.

"The arrows require in the aggregate much more labor than the bow. Any hard, tough, straight-grained wood is used. It is scraped to proper size and shape, and must be perfectly round. The head is either of stone or iron—of late years almost exclusively of iron, for stone of the necessary hardness is extremely difficult to work, and twenty or more stones are spoiled or broken for each arrow-head made.

"Under the most favorable circumstances, however, the most skillful Indian workman can not hope to complete more than a single arrow in a hard day's work. In a short fight, or an exciting dash after game, he will expend as many arrows as will keep him busily at work for a month to replace.†

"The constructive industry of the men was confined principally to the making of arms, bows, arrows, shields, and spears. These were all objects in which they took great pride. The favorite material for bows

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* Letter from I. Allen, Stillwater, Mont.

† Dodge, *Plains of the Great West*, Putnam, 1877, pp. 348, 349.

was *bois d'arc* (*Maclura aurantiaca*). When these could not be obtained hickory or coffee bean (*Gymnocladus Canadensis*) was used. The name *ti-rak-is*, bow, seem to indicate that bows were once made of bone, the ribs of the buffalo or other large animal, skillfully fitted and wrapped throughout with sinew. Forty years ago bows of this kind, and also of elk horn were occasionally found in use. Choice bows were sometimes made of red cedar, and if carefully used answered well, but were extremely liable to be shattered by any rough handling. The making of a good bow was a task involving long and painstaking labor. It was wrought into shape only a little at a time, being repeatedly oiled meanwhile, and constantly handled to keep the wood pliable. When finished the bow was sometimes wrapped with sinew and its strength thereby greatly increased. The string was of sinew from the back of the buffalo. As soon as the sinew was taken from the animal the particles of flesh adhering were scraped off and the minute fibres carefully separated. The best of these were selected and twisted into a string of uniform size and elasticity. One end of this string was fastened securely in place upon the bow, and the other furnished with a loop so adjusted that in an instant, as occasion required, the bow might be strung or unstrung.

"According to Dunbar much labor was spent by the Pawnees in the construction of arrows. The shafts were made from sprouts of dogwood (*Cornus stolonifera*). The bark was removed and the rods were rubbed between two grooved stones, held firmly together in one hand till reduced to a proper size and smoothness. The head, made of hoop iron, was then inserted in one end of the shaft and bound in position with sinew. The back end of the shaft was now furnished with a triple row of feathers attached by means of glue and sinew and the end notched to fit the bowspring. With a small chisel-like instrument three slight grooves or channels were cut along the shaft between the head and the feathers and the arrow was complete. Various reasons were assigned for this channeling. Some claimed that it caused the arrow to adhere more firmly in the wound; others that it was simply designed to facilitate the flow of blood. The manufacture of arrows, as of bows, was a slow and irksome process. Three or four were probably the limit of a day's work, even after the rough material was already at hand. So exact were they in making them that not only were the arrows of different tribes readily distinguishable, but even individuals could recognize their own arrows when thrown together with those of others of the same band. Disputes sometimes arose after the slaughter of a herd of buffalo as to whose some particular carcass rightfully was. If the arrow still remained in the body the question was easily decided by drawing it out and examining the make of it. Some Indians made two kinds of arrows, one for hunting and another for war. In the latter the head was so fastened that when an attempt was made to draw the shaft from a wound the head was detached and remained in the body of the victim. The Pawnee never used such. When once he had possessed himself of a good bow and a supply of arrows the Pawnee was as solicitous in the care of them as a hunter would be of a choice rifle. The bow, if not in actual service, was kept close in its case, and the arrows in the quiver. Great pains were taken that they should not become by any chance wet, and much time was spent handling them, that the bow should not lose its spring and the arrows should not warp. The average length of the former was 4 feet; of the latter 26 inches."*

*J. B. Dunbar: *Pawnee Indians*, sec. 20.

The case for the bow and the quiver are of the skin of some animal, often of otter, fastened to each other; and to the latter the tail of the animal at full length is appended. The bow is partly covered with elk horn, has a very strong string of twisted sinews of animals, and is wound round in different places with the same to strengthen it. The bow is often adorned with colored cloth, porcupine quills and white strips of ermine.*

"The Pawnee bow case and quiver were made of skin, dressed to be impervious to moisture. The usual material was elk skin. Indians who could afford it sometimes made a quiver and case of the skin of an otter or panther. In removing a skin which was to be used for this purpose from the carcass, care was exercised that every particle of the skin, that of the head, tail, and even the claws, should be retained, and appear in the case when finally made up. Cases of this make, with their heavy coating of fur virtually waterproof, were very highly prized."†

"The bow-makers of both the Hupa and Klamath tribes," says Ray, "are specialists, and the trade is now confined to a very few old men. I have here seen no man under 40 years of age that could make a bow or an arrow, and only one old man who could make a stone arrow-head.

"To make a bow, the wood of a yew sapling 2½ to 3 inches in diameter is selected and rough-hewn to shape, the heart side inward and the back carefully smoothed to the form of the back of the bow. The sinew is laid on while the wood is green and held in place until dry by means of a twine wrapping. In this condition it is hung in the sweat house until the wood is thoroughly seasoned, when it is finished and strung, and in some cases the back is varnished and painted. The most delicate part of the operation is to get the proper tension on the sinew backing. If too tight the wood crimps or splinters when the bow is strung, and a lack of proper tension leaves the bow weak and worthless. When the bow is seasoned it has a reverse curve of about 3 inches.

"The sinew for the backing and bow-string is taken from the back and the hind leg of the deer at the time of killing, and dried for future use. When required it is soaked until pliable, stripped into fine shreds and laid on by commencing at each end and terminating at the center of the bow. The sinew is slightly twisted and dried before it is placed on the bow.

"The glue used to fix the backing is obtained by boiling the gland of the lower jaw and the nose of the sturgeon. This is dried in balls and preserved for use, and is prepared by simply dipping it in warm water and rubbing it on the wood.

"The arrow shafts are usually made from the wood of the wild currant, and are worked to shape with a knife and tried by the eye. After roughing they are allowed to season and are then finished. Any curves are taken out with a straightener, made of a piece of hard wood, spindle shaped and perforated in the middle. The arrow-heads used in war and for big game are usually made from flint and obsidian, and more recently of iron and steel. The flakes for the stone heads are knocked off by means of a pitching tool of a deer antler. The stone heads are made with a chipper composed of a crooked handle, to which is lashed

* Maximilian, *Travels*, London, 1843, p. 195, mentions that the Sioux bows are similar.

† J. B. Dunbar: *The Pawnee Indians*.

a short piece of antler precisely similar to those which I collected at Point Barrow. The work is held in the left hand on a pad and flaked off by pressure with a tool in the right hand in exactly the same manner as I found the Innuits doing in northern Alaska.

"The bows made by these people are effective for game up to 50 or 75 yards, and would inflict a serious wound at 100 yards. At 50 yards the arrows will penetrate a deer from 5 to 10 inches. I never heard of one passing entirely through a deer.*

"Eells says that "bows and arrows are used at present by the Twana in Washington state only as playthings, and are very poor; but formerly they were very common. The bows were about 3 feet long, and were made of yew wood, the strings of sinews or the intestines of raccoons. The arrows were about 2½ feet long, were made of cedar, with feathered shafts, and points of stone, and of nails, after they obtained them; and the quiver of wolf skin. Arrow-heads are sometimes made of brass or iron, 2 or 3 inches long, half an inch wide, and very thin, and also of very hard wood, 5 inches long, and round. Sometimes, for birds, they are made of iron-wood, about 5 inches long, with two prongs, one of them being half an inch shorter than the other."†

According to Capt. Wilkes the Klamet bows and arrows are made the first of yew about 3 feet long, flat, 1½ to 2 inches wide, backed with sinew and painted. The arrows are over 30 inches long, some of close-grained wood, a species of Spiraca, others of reed. Feathers are 5 to 8 inches long. The barbed head of obsidian is inserted in a fore shaft 3 to 5 inches long. This is left in the wound. Shallow blood channels are sometimes cut in the shaft. The bow is held horizontally, braced by the thumb of the left hand and drawn by the thumb and three fingers of right hand. The chest is thrown back and the right leg forward in shooting. Quivers are of deer, raccoon, or wild-cat skins.‡

The Clallam bows were short and small, made of yew. The arrows were small and pointed with bone or iron.§ The Clallams are one of the Salishan tribes from whom Wilkes gathered many bows and arrows, now in the National Museum. The arrow shafts are of cedar, and have a large, bulbous nock, wrapped with birch bark. Some of them have two-barbed points of wood, bone, or metal.

Bows of the Shushwap were formerly made chiefly of wood of the juniper (*Juniperus occidentalis*), named poontlp. They were also sometimes made of yew (*Taxus brevifolia*), named skin-ik, though this tree is scarcely to be found in the Shushwap country. It is reported however to grow far up in the North Thompson Valley. The bow was often covered on its outer surface with the skin of a rattlesnake, which was glued on in the same manner which was customary among some of the tribes of the Great Plains. Arrows were made of the wood of the service berry. Arrow-heads and spear-heads were made of various kinds of stone, always chipped.||

* P. H. Ray.

† Rev. M. Eells, Hayden's *Bull.*, 1877, 3, pp. 78–79.

‡ Cf. Wilkes, *Narrative*, vol. v., p. 239.

§ Wilkes, *Narrative*, IV, 299.

|| "People of British Columbia." G. M. Dawson, p. 17.

"The native bow in Vancouver's island is beautifully formed. It is generally made of yew or crab-apple wood, and is 3½ feet long, with about 2 inches at each end turned sharply backward from the string. The string is a piece of dried seal gut, deer sinew, or twisted bark. The arrows about 20 inches long, and are made of pine or cedar, tipped with 6 inches of serrated bone, or with two unbarred bone or iron prongs. I have never seen an Aht arrow with a barbed head." (Sproat's *Scenes*, p. 82.)

"Having now, to a great extent, discarded the use of the traditional tomahawk and spear. Many of these weapons are, however, still preserved as heirlooms among them." (Barrett-Lennards Trav., p. 42.)

"No bows and arrows. Generally fight hand to hand, and not with missiles." (Fitzwilliam's Evidence, *in Hudson Bay Co., Rept.*, 1857, 115.)*

"The arrows and spears in Puget Sound were usually pointed with bone; the bows were of yew, and though short, were of great power. Vancouver describes a superior bow used at Puget Sound. It was from 2½ to 3 feet long, made from a naturally curved piece of yew, whose concave side became the convex of the bow, and to the whole length of this side a strip of elastic hide or serpent skin was attached so firmly by a kind of cement as to become almost a part of the wood. This lining added greatly to the strength of the bow, and was not affected by moisture. The bowstring was made of sinew." Vancouver's *Voy.*, vol. I, p. 253.

"At Gray Harbor the bows were somewhat more circular than else where." (Vancouver's *Voy.*, vol. II, p. 84; Wilkes's *Nar. in U. S. Exploring Expedition*, pp. 14, 319; Kane's *Wand.*, pp. 209, 210.)†

Lieut. Allen, U. S. Army, has described the excessive pains which the Copper River Indians bestow upon the fashioning and caring for their bows. There are no first rate, tough, elastic woods near them. Birch and willow and such soft species are the only stock in trade. And yet, by dint of heating or toasting, boiling, greasing, and rubbing down they convert these poor materials into excellent arms. It is here that the wooded wrist guard or bridge is attached to the grip on the inside.

The Hong Kutchin Indians (Athapascan family) closely allied with Lieut. Allen's people, make their bows of willow after the same painstaking fashion, and their arrows of pine. The bows are almost straight, and in order to prevent the string from lacerating the wrist they do not wear a wrist guard, but lash a bit of wood to the inside of the grip (*see* Plate II). The Kutchin tribes all use a similar bow, but do without the guard. The quiver is simply a bag of skin worn under the left arm. It has two loops for the bow and the arrows are inserted notch down.‡

"The arrow-heads of the Kutchin are of bone for wild fowl, or bone tipped with iron for moose or deer; the bow is about 5 feet long, and that of the Hong-Kutchin is furnished with a small piece of wood 3 inches long by 1½ broad, and nearly 2 thick, which projects close to the part grasped by the hand. This piece catches the string and prevents it from striking the hand, for the bow is not bent much. There are no individuals whose trade is to make spears, bows, or arrows."

* See Bancroft, Native Races, vol. I, p. 188.

† *id.* 214–215.

‡ Jones, *Smithsonian Report,* 1866, pp. 322, 324.

"The Kutchin still retain the bow, which is of the same shape through all the tribes, with the exception of the small guard in the Hong-Kutchin bow, mentioned before. The quiver is the same, and worn under the left arm; it is furnished with two small loops to hold the bow, thus leaving the hunter both hands free to use his gun. The arrows are placed in the quiver with the notch downwards. The Kutchin are not expert with the bow; no doubt they were better shots before firearms were introduced among them. The bow is made of willow and will not send an arrow with sufficient force to kill a deer more than from 50 to 60 yards. The arrows are made of pine."*

Father Morice says that "the only pursuit for which our Dene may be said to have been amply provided with home-made implements was war and its allied occupation, hunting. The offensive weapons in use among them were arrows, spears, lances, and *casse-tetes*.

"The only really polished stone implement of Dene manufacture was the *caelh* or *casse tete*. The specimen illustrated is of a hard granite stone. A variety of that weapon, similar in form, but more elongated (being at least twice as long) was usually made of cariboo horn.

"Apart from the common arrows, the Carriers made use of two other varieties of missiles of Sekanais origin. The heads of both kinds were made from cariboo horn. The first of these, called *krachaenkwaelh* (cut arrow) by the Carriers, was conical in form and not less than 6 inches in length. The broader extremity thereof was hollowed out to receive a wooden shaft which served to dart it off from the bow like a common arrow, with this difference, however, that when in motion the horn point detached itself from the shaft. This projectile was deadly, and intended only for use against an enemy or for killing large game. To shoot smaller game, such as grouse, rabbits, etc., they had recourse to a curiously-wrought triple arrow head consisting of three flat pieces of bone or horn triangular in shape and not unlike the feathers on a sea-otter arrow. These plates were seized to the arrow shaft in several places by sinew passing through the plates and around the wood. The manner of fastening to the shaft was similar to that delineated in Morice's fig. 14."

The knives were ordinarily made of the common arrow-head flint, but those of beaver teeth were more esteemed.

"Their arrow, common arrow heads, were of two kinds, bone and flint. The first were made of the front teeth of the beaver, reduced by scraping to the required shape. They were reputed the most effective. Flint arrow-heads were of different sizes, forms, and material. They are produced in Morice's paper for the sake of comparison with those used by the mound-builders of Illinois and other States of the American Union with which they will be found identical in shape and material, though a distance of at least 2,000 miles separate the Aborigines who made them. He says the 'two marked A and B may be described as the typical arrow-heads of the Western Denes, and are of the blackish resonant flint, generally used in the fabrication of aboriginal weapons. C and D are composed of a semi-translucent bluish variety of siliceous stone not so common and consequently more prized than the ordinary arrow-flint. E represents the most beautiful of all the Dene arrow-heads in my possession. It has been ingeniously chipped from a hard crystalline species of flint, and its form and finish display evidences of, I should say, exceptionally good workmanship. Some are also formed of a whitish siliceous pebble; but the points made therewith are, as a rule, of a rather rough description.'"

* Jones, *S. R.*, 1866, p. 321.

"The regular hunting or war bow of the Tse'kehne was of mountain maple (*Acer glabrum*, Tow) and 5½ feet or more in length. The edges, both inner and outer, were smoothened over so as to permit of strips of unplaited sinew being twisted around to insure therefor the necessary strength. These pieces of sinew were fastened on with a glue obtained from the sturgeon sound, which also did service for all kinds of gluing purposes among each of the three tribes, while still in their prehistoric period. The central part of the bow, which was so thick as to appear almost rectangular, was finally covered with a tissue of differently-tinged porcupine quills.

"Great care was taken to obtain a bow-string impermeable to snow and rain. With this object in view, delicate threads of sinew were twisted together and afterwards rubbed over with sturgeon glue. This first string was then gradually strengthened by additional sinew threads twisted around the first and main cord, each overlaying of sinew being thoroughly saturated with glue. Finally when the string had attained a sufficient thickness for efficient service it was repeatedly rubbed over with gum of the black pine (*Abies balsamea*).

"A less elaborate bow (fig. 31) is still to this very day in use among the Tse'kehne in connection with the blunt arrow already mentioned. It is of seasoned willow (*Salix longifolia*), and being devoid of any sinew backing or other strengthening device, its edges are more angular than those of fig. 30. Its string consists merely of a double line of cariboo skin slightly twisted together. The specimen figured above measures 4 feet 10 inches.

"The Carrier bow was never much more than 4 feet in length, and the wooden part of it was invariably juniper (*J. occidentalis*). Instead of being twisted around as in the Tse'kehne bow, the threads of sinew were glued on the back after the fashion of the Eskimo bow, with this difference, however, that in the Carrier weapon the sinew was not plaited. When a layer of thin sinew strips had been fastened lengthwise on the entire back of the bow, it was allowed to dry, after which others were successively added until the desired strength had been obtained. A process analogous to that whereby the Tse'kehne bow-string was made was followed in cording the string of the Carrier bow."*

"The most powerful as well as most artistic weapon is the bow. It is made of beech or spruce in three pieces, curving in opposite direction, and ingeniously bound by twisted sinews, so as to give the greatest possible strength. Arrows, as well as spears, lances, and darts, are of white spruce, and pointed with bone, ivory, flint, and slate.

"They have two sorts of bows, arrows pointed with iron, flint, and bone, or blunt for birds. (*Simpson Nar.*, 123.)

"They ascended the Mackenzie in former times as far as the Ramparts to obtain flinty slate for lance and arrow-points. (Richardson's *Jour.*, vol. I, p. 213.)

"One weapon was a walrus tooth fixed to the end of a wooden staff. (Beechey's *Voy.*, vol. I, p. 343.)

"At Coppermine River arrows are pointed with slate or copper. (Hearne's *Travels*, pp. 161–169.") †

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* Father A. G. Morice, *Trans. Canad. Inst.*, Toronto, 1894, IV, 58, 59.

† See Bancroft, *N. R.* vol. I, p. 59.

EXPLANATION OF PLATE XXXVII.

THE MAKING AND MOUNTING OF AN ARROW POINT.

FIG. 1. Knocking off chips from a core of obsidian by means of the stone hammer and pitching tool of antler; one person operating.

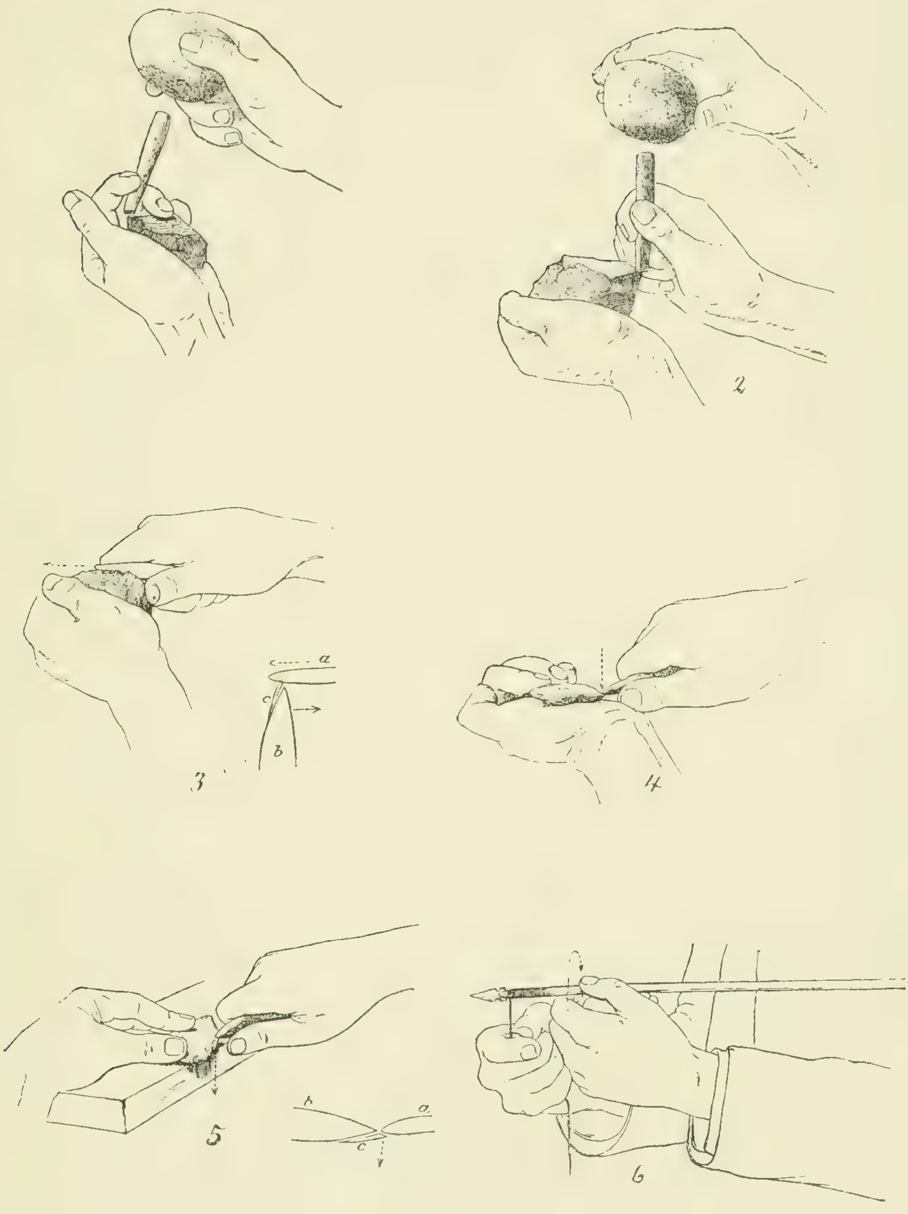
FIG. 2. Knocking off chips from a core of obsidian by means of the stone hammer and pitching tool of antler; two persons operating.

FIG. 3. Pressing off flakes from a blade of siliceous stone by means of the bone flaker, the operator holding the blade against the ball of the thumb and pressing from him.

FIG. 4. Pressing off flakes from a blade of siliceous stone by means of a bone flaker, the operator holding the blade on the palm of the hand and pressing downward. Frequently the hand is gloved or a bit of rawhide is first laid upon the palm.

FIG. 5. Pressing off flakes from a bit of siliceous stone by means of the bone flaker, the operator holding the block upon a bit of wood with his left hand and pressing downward with the right. This is a very effectual mode of working.

FIG. 6. Fastening the arrowhead upon the shaft by means of a filament of moist sinew. The shaft is held firmly under the left arm for a bearing, held and revolved by the left hand, and the moist filament of sinew is held tight and guided by the right hand.



THE MAKING AND MOUNTING OF AN ARROW-POINT.
(After Holmes and Hough.)

EXPLANATION OF PLATE XXXVIII.

Materials of the Arrow-Maker.

This plate shows the typical collection of material as it is prepared for use by the Hupa arrow-maker (Athapascan stock), northern California. The same outfit would do for any other craftsman of this class throughout the temperate regions of North America, only the form of the tool would be changed.

Fig. 1. The shaft. A simple twig or rod or switch of any suitable wood. If the pith be thick, the rod is treated much as a reed. If it be meager the twig may be whittled away at certain parts to change the form. Among certain tribes the arrow shafts are made of sections split from large sticks.

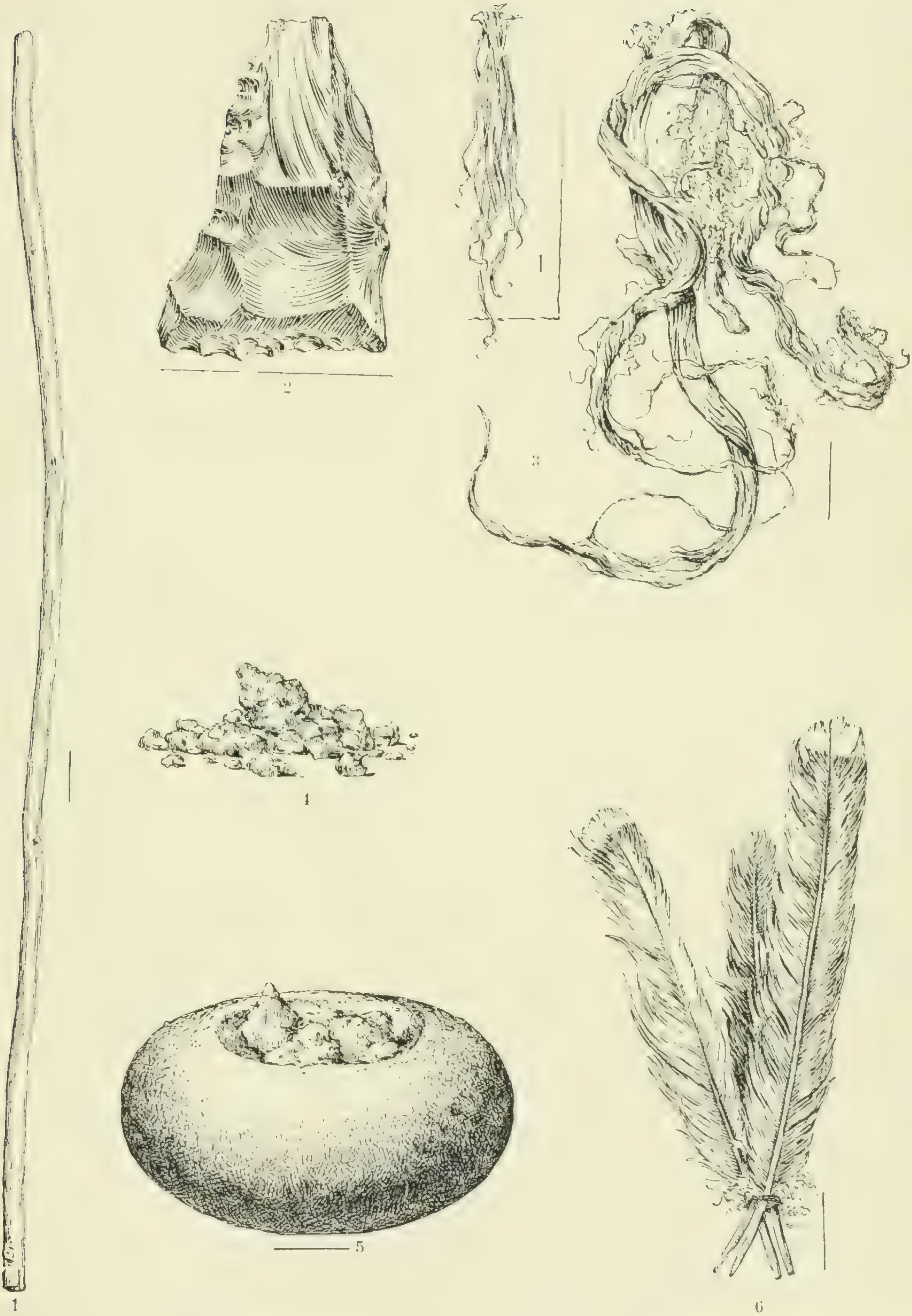
Fig. 2. The point. The material is as varied as stone with conchoidal fracture may be. Spalls are struck off and made into arrowheads by a multitude of processes explained in the text.

Fig. 3. Sinew for seizing. The figure shows its appearance as it is dried and saved up for future use.

Fig. 4. Gum. The exudations from trees or glue from fish or animal substances used to hold the feather to the shaft, the head in its place, or to smear over the sinew seizing to give it a smooth and homogeneous appearance.

Fig. 5. Paint mortar. The paint mortars of the American aborigines are discoidal stones usually, with a shallow cavity. In this cavity ochers and other paint substances are ground, mixed with the grease of animals or with water, and used in decorating both bows and arrows.

Fig. 6. Feathers. The plume is stripped off with a small portion of the midrib, seized to the shaft, and trimmed in many ways.



MATERIALS OF THE ARROW-MAKER.

EXPLANATION OF PLATE XXXIX.

TOOLS OF THE ARROW-MAKER.

This plate shows the tools of the arrow-maker.

FIG. 1. SHAFT STRAIGHTENER. The example figured is from the Hupa (Athapascan) tribe of California. It is a piece of yew ten inches long, spindle-shaped and having an oblong hole through the middle. The arrow shaft is drawn through the hole and straightened by pressure on the ends of the tool.

FIG. 2. THE GLUE STICK, which is simply a bit of wood having one end covered with glue, used like a tinner's soldering iron.

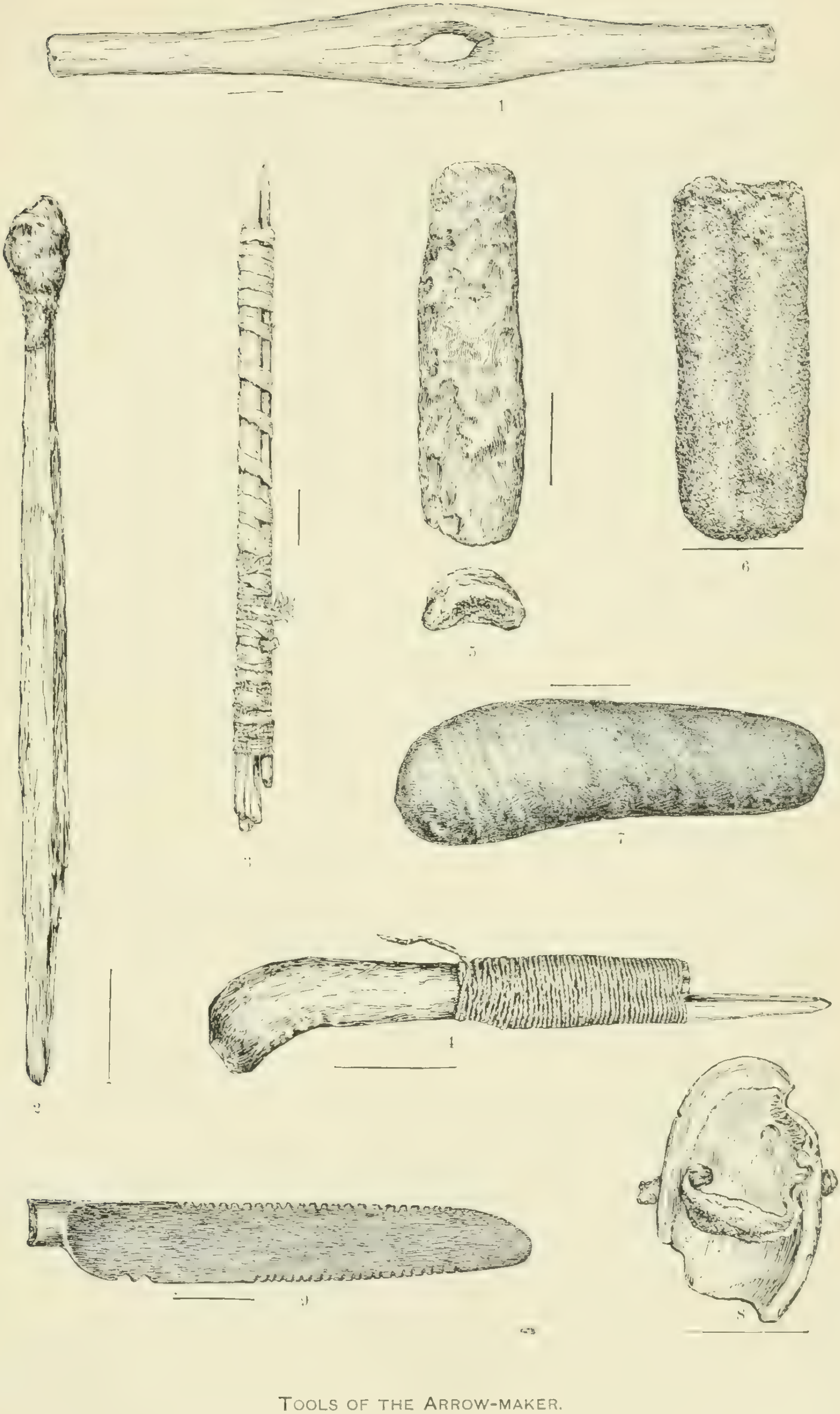
FIGS. 3 and 4. ARROWHEAD CHIPPERS. Showing the primitive method of joining the working parts to the handle. One point is a bit of bone, the other a rod of soft iron, which in this example replaces one of bone or antler.

FIG. 5. THE PITCHING TOOL. A column of antler used like a cold chisel in knocking off spalls or flakes or blades by means of some kind of hammer.

FIGS. 6 and 7. RASPING AND POLISHING STONES. All the American tribes used coarse sandstone for wood rasps, and in the making of arrow shafts cut grooves in the rasp to give rotundity to the wood. The polishing was done with finer sandstone, shagreen, siliceous grass, etc.

FIG. 8. GLUE SHELL. An implement made of muscle shell worn over the finger and employed in smoothing down glue and sinew on bows and arrows.

FIG. 9. SAW. In this example an old case knife blade, hacked on the edge. In primitive times wood saws were made of chipped siliceous stone.



TOOLS OF THE ARROW-MAKER.

EXPLANATION OF PLATE XL.

The Parts of an Arrow.

The dissected arrow is shown in such fashion that the parts of a highly complex example may be understood.

A complete arrow. Foreshafted type, found among the tribes of Oregon and northern California.

The ideas made specially prominent are:

Fig. 1. The method of inserting the foreshaft into the end of the shaft.

Fig. 2. The attachment of the head to the barb piece by diagonal lashing of sinew and the union of the stone head with the barb piece of bone attached to the foreshaft.

Fig. 3. The laying on of the feathering in one example having what is called the "rifling" of the arrow.

Fig. 4. The foreshaft before the head is attached, showing especially the neat manner of its union with the shaft.

Fig. 5. The painted bands or ribands of the shaftment, called by a variety of names.

Fig. 6. The relation of the nock to the pithy wood of the shaft.

THE PARTS OF AN ARROW.

EXPLANATION OF PLATE XLI.

ARROWS OF SOUTHERN CALIFORNIA AND ARIZONA.

FIG. 1. SHAFT of reed. Foreshaft, a rod of hard wood inserted into the end of the shaft, which is tapered down and seized with sinew. Head, of jasper inserted into a deep notch in the end of the foreshaft and held in place by diagonal lashings of sinew and mesquite gum. Feathers, three, seized at the ends with sinew. Shaft, 26½ inches; foreshaft, 7½ inches.

Cat. No. 11783, U. S. N. M. Moki Indians, Arizona. Collected by Bureau of Ethnology.

NOTE.—The Moki Indians are of Shoshonean stock, live in pueblos, and use the Mohave type of arrows.

FIG. 2. SHAFT, of reed. Foreshaft, a rod of hard wood inserted into the end of the shaft and seized with sinew. Head of chalcedony, triangular, inserted into a "saw cut" at the end of the foreshaft, and held in place by mesquit gum laid on so as to form an unbroken surface between the foreshaft and the head. The end of the foreshaft is seized with sinew. Shaftment ornamented with a band of red and a spiral band in black. Nock, cylindrical. Notch, U-shaped. Feathers, three, seized with untwisted sinew. Length, 37 inches.

Cat. No. 1796, U. S. N. M. Mohave Indians, southern California. Collected by Edward Palmer.

NOTE.—To the right of this example is shown a shorter type of feathering and ornamented shaftment by the same tribe.

FIG. 3. SHAFT, rod of hard wood. Head made from a piece of an old pair of scissors inserted into the split end of the shaft. Feathers, three, lashed at the ends with sinew. Nock spreading, and notch a long deep incision. Length of arrow, 25 inches.

Mohave Indians.

NOTE.—This arrow, though accredited to the Mohave Indians, belongs to a much more northern type, and if properly labeled by the collector shows the effect of commerce and migration.

FIG. 4. SHAFT, a rod of hard wood. Shaftment daubed with bands of red paint. Feathers, three, fastened at the ends with sinew. The nock is cylindrical. The notch, parallel sided. Foreshaft short, of hard wood, inserted neatly into the end of the shaft and daubed with brown paint. Head, of bottle-glass, inserted slightly into the foreshaft and held in place by a diagonal seizing of sinew. Total length, 34½ inches.

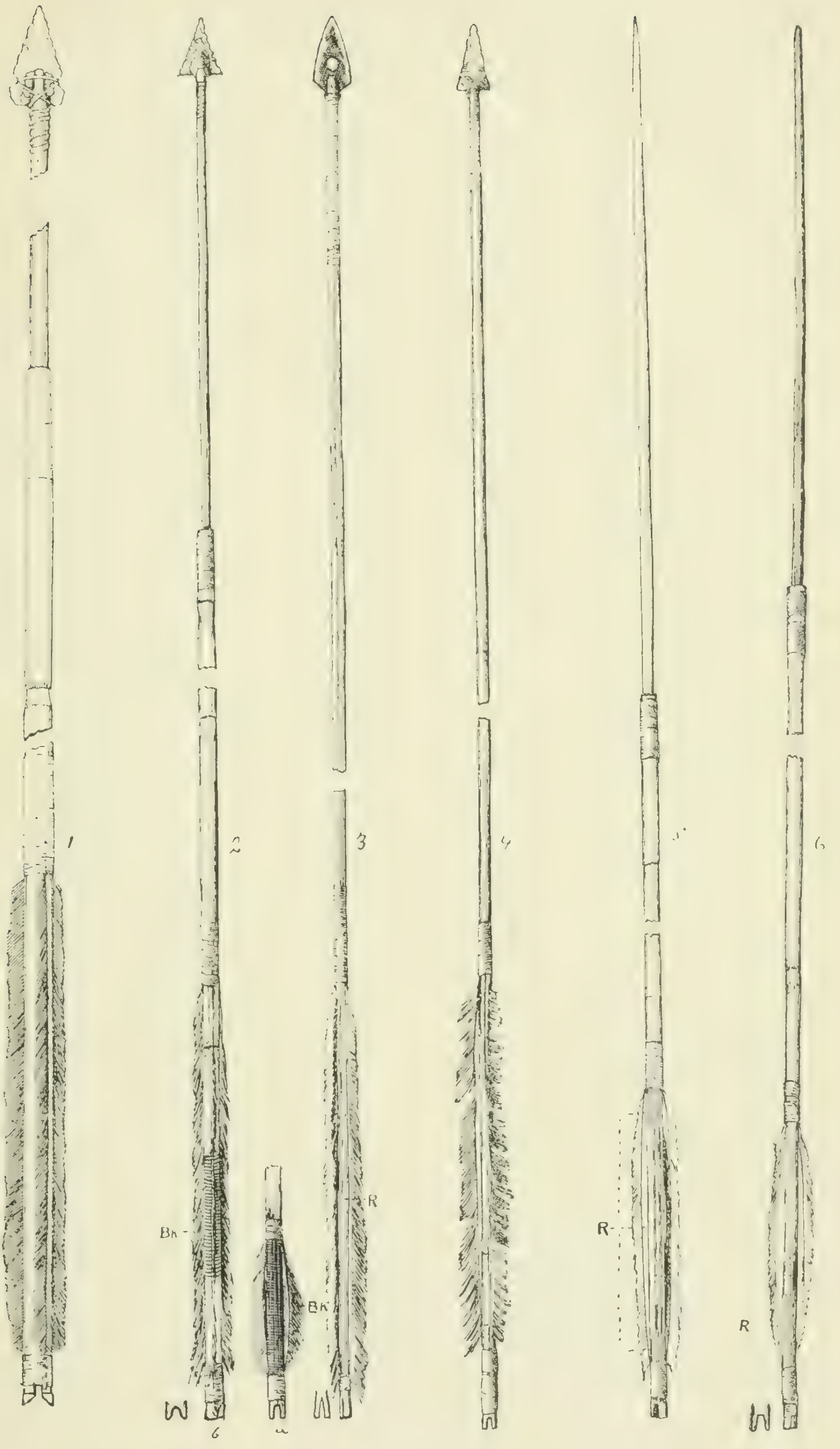
Cat. No. 128431, U. S. N. M. Yuma Indians. Collected by Col. James Stevenson.

FIG. 5. SHAFT, of reed. The shaftment is ornamented with two bands of red paint connected by longitudinal stripes. Feathers, three, seized with sinew. Nock, cylindrical. The sides of the notch are made parallel by cutting into the reed on either side and splitting out a little piece. The point and foreshaft of this arrow are one, made of a piece of hard wood inserted into the reed-shaft and seized with sinew, and at the other extremity sharpened to a long tapering point. Length of shaft, 2 feet 1¾ inches; foreshaft, 12 inches.

Cat. No. 76176, U. S. N. M. Cocopa Indians, Mexico. Collected by Edward Palmer.

FIG. 6. SHAFT, of reed. Foreshaft, square bit of mesquite wood inserted into the end of the shaft and seized with sinew. Feathers, three, lashed with sinew at the ends. Shaftment ornamented with a band of red. This specimen is rudely made, showing a degenerate art. Length of shaft, 28 inches; foreshaft, 10 inches.

Cat. No. 9072, U. S. N. M. Yaquis Indians. Collected by Edward Palmer.



ARROWS OF SOUTHERN CALIFORNIA AND ARIZONA.

EXPLANATION OF PLATE XLII.

ARROWS OF THE PUEBLO REGION AND SOUTHWESTERN UNITED STATES.

FIG. 1. SHAFT, a small stem or twig, with very shallow and sinuous shaft streaks. Feathers, three, loosely held on and seized at either end with sinew. At the edges of the shaftment are bands of brown and black. The nock is slightly spreading. The notch is U-shaped. Point, of iron, leaf-shaped and slender, the tang inserted in a notch at the end of the shaft and seized with sinew. This arrow, like most of those collected from this tribe, is very coarsely made. Total length of shaft, 24½ inches.

Cat. No. 75678, U. S. N. M. Zuni Indians. Collected by James Stevenson.

FIG. 2. SHAFT, of reed. Foreshaft, a twig, perhaps of greasewood set into the end of the reed of the shaft and seized with sinew. The stone head is sagittate, let into the head of the foreshaft, and fastened first with sinew and then covered with gum. The whole foreshaft is covered with dark gum. Feathers, three, seized at the ends with sinew and trimmed down along the margins. It is possible that these reed arrows of the Oraibi are derived from the Mohave or Apache further south. Length, shaft, 24 inches; foreshaft, 12 inches.

Cat. No. 11780, U. S. N. M. Hopi or Moki pueblo of Oraibi (Shoshonean) Arizona. Collected by J. W. Powell.

FIG. 3. SHAFT, of twig; shaft streaks very wavy and crowded. In comparison with the size of the arrow the feathers are very wide and conspicuous. They are laid close to the shaftment and are seized with sinew. The nock is slightly expanding. Notch, angular; head of jasper, small, inserted into the end of the shaft and seized with a diagonal lashing of sinew, which passes also once transversely. Total length, 26 inches. Especial attention is called to the existence of the reed arrow (fig. 2) and the simple arrow in the same pueblo.

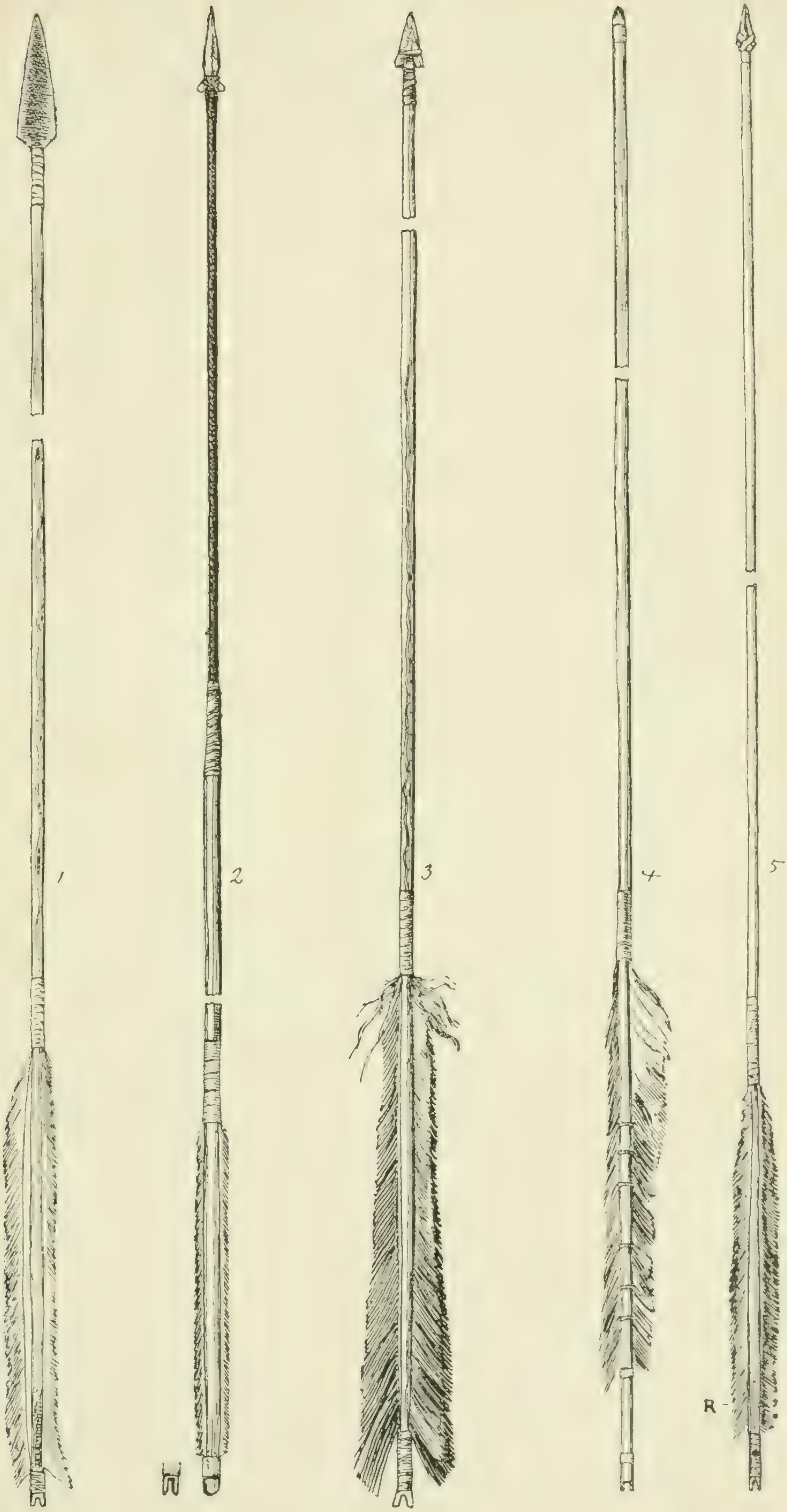
Cat. No. 22594, U. S. N. M. Hopi or Moki Indians, Arizona. Collected by Maj. J. W. Powell.

FIG. 4. SHAFT, a single rod bluntly pointed at the head and seized with sinew. Feathers, three, neatly seized with sinew at the fore end and by seven narrow bands of sinew behind. The feathers are far from the nock, which is also bound with sinew. This type of feathering is rare in America. Length, 30 inches.

Cat. No. 165573, U. S. N. M. Pima Indians, Salado Valley, Arizona. Collected by F. Webb Hodge.

FIG. 5. This arrow is similar to that shown in fig. 4, but differing from it in having a small stone head wrapped crosswise, in having the feathers nearer the nock, and in the omission of the intervening wrappings of sinew on the feather.

Cat. No. 76021, U. S. N. M. Pimo Indians. Collected by Dr. Edward Palmer.



ARROWS OF THE PUEBLO REGION AND SOUTHWESTERN UNITED STATES.

EXPLANATION OF PLATE XLIII.

ARROWS OF APACHE TRIBES, SOUTHWESTERN UNITED STATES.

FIG. 1. The shaft is of osier, with shaft streaks nearly straight. Shaftment tapering backwards and banded with red and green paint. Nock, swallow-tail shaped. Feathers, three, seized at their ends with sinew and extending off from the shaft at the middle. The front part of the feathering is ornamented with tufts of down. The delicate blade of iron forming the head is inserted into a "saw cut" in the end of the shaft and seized with sinew. Total length, 25½ inches.

Cat. No. 6964, U. S. N. M. Comanche Indians, of Texas. Collected by Dr. E. Palmer, U. S. Army.

FIG. 2. SHAFT, of reed. The shaftment is ornamented with bands of red and black. Feathers, three, seized with sinew. Notch, parallel-sided. The foreshaft, of hard wood, fits into the end of the reed shaft and is seized with sinew. It is daubed with brown paint. Head, of jasper, incurved at the base and notched on the sides. It is inserted into the end of the foreshaft and fastened by a diagonal seizing of sinew and further secured by mesquite gum. Total length of shaft, 37½ inches.

Cat. No. 5519, U. S. N. M. Apache Indians, of Arizona. Collected by Dr. Edward Palmer.

FIG. 3. SHAFT, of rhus, painted red. Feathers, three, seized with sinew, standing off from the shaftment. The nock is cylindrical and the notch is rectangular. Head, of old hoop iron, inserted in a notch in the end of the shaft and seized with sinew. This specimen is very roughly made. The total length of the shaft is 25 inches.

Cat. No. 25512, U. S. N. M. Apache Indians. Collected by Dr. J. B. White, U. S. Army.

FIG. 4. SHAFT, of hard wood. Iron head let in at the end of the shaft. Feathers, three, seized with sinew. Shaft painted blue. Shaftment bound with yellow, blue, and red streaks. Length, shaft, 2 feet 4 inches.

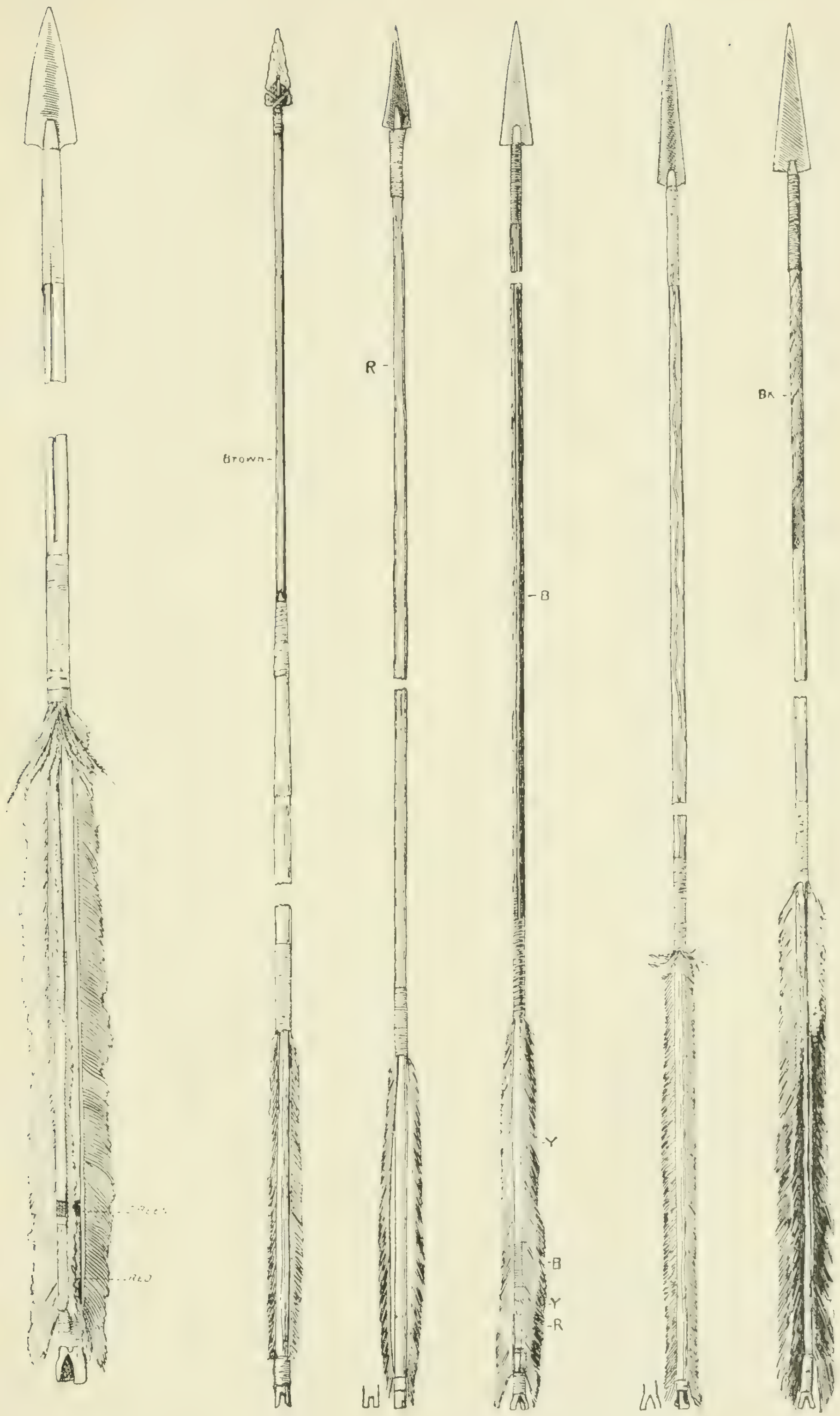
Cat. No. 130307, U. S. N. M. Apache Indians, Athapascan stock, Arizona. Collected by Dr. T. C. Scantling, U. S. Army.

FIG. 5. SHAFT, of osier. Has three shaft streaks, two nearly straight and one a wavy line. The shaftment is ornamented with bands of red and blue. Feathers, three, attached at their ends by a seizing of sinew and glued to the shaft. Near the seizing is a bunch of downy feathers, left for the purpose of ornamentation. Nock, widely spread. Notch, angular. The head is a tapering blade of iron, a portion of which, with the tang, is inserted into a "saw cut" and neatly seized with sinew. Total length, 27 inches.

FIG. 6. This arrow is similar to No. 5 A, excepting a little ornamentation on the front of the shaft. Total length, 24½ inches.

NOTE.—Both of these arrows are perfect of their kind. It is difficult to conceive how a more deadly missile could be made.

Cat. No. A and B 150450, U. S. N. M. Navajo Indians. Collected by Dr. Washington Matthews, U. S. Army.



ARROWS OF APACHE TRIBES, SOUTHWESTERN UNITED STATES.

EXPLANATION OF PLATE XLIV.

ARROWS FROM VARIOUS TRIBES OF THE GREAT INTERIOR BASIN.

FIG. 1. SHAFT, of rhus. Shaftment painted with red and brown paint. Feathers, three, laid on close to the shaftment and neatly seized with sinew. The nock is cylindrical and the notch U-shaped. Head, of chalcedony, inserted into a shallow notch at the end of the shaftment, seized with sinew, and afterward cemented with mesquite gum. This is a beautifully made specimen. Total length of shaft, 27 inches.

Cat. No. 14699, U. S. N. M. Piute Indians. Collected by Major J. W. Powell.

FIG. 2. SHAFT, of hard wood, trimmed down. Head, of hoop iron, fastened on with lashing of thread. Feathers, three, seized with sinew, glued down and trimmed along the margins. Nock, swallow-tailed, and the feathering extends beyond the nock. Length, shaft, 2 feet 3 inches.

Cat. No. 131238, U. S. N. M. Shoshonean. Collected by G. Brown Goode.

FIG. 3. Gambling arrow of the Apache Indians. Shaft, painted blue; three tolerably straight blood streaks. Feathers, three, seized with sinew. Nock in form of swallow's tail. Notch, acute angular. The point of wood is a continuation of the shaft, triangular in cross-section. The ornamentation on the point consists of lozenge-shaped cavities and furrows filled with red and blue paint. In a series of these arrows no two are ornamented exactly alike. Used in divination and gambling. Mr. Frank H. Cushing connects the divination by throwing a bunch of these arrows with the position of the arrows in the Assyrian cuneiform inscriptions.

Cat. No. 73268, U. S. N. M. Apache Indians. Collected by G. H. Leigh.

FIG. 4. A rude unfinished arrow with shaft unstraightened. Three feathers loosely attached to the shaft with sinew, the whole showing the degeneration of the art of arrow-making in ceremonial usages.

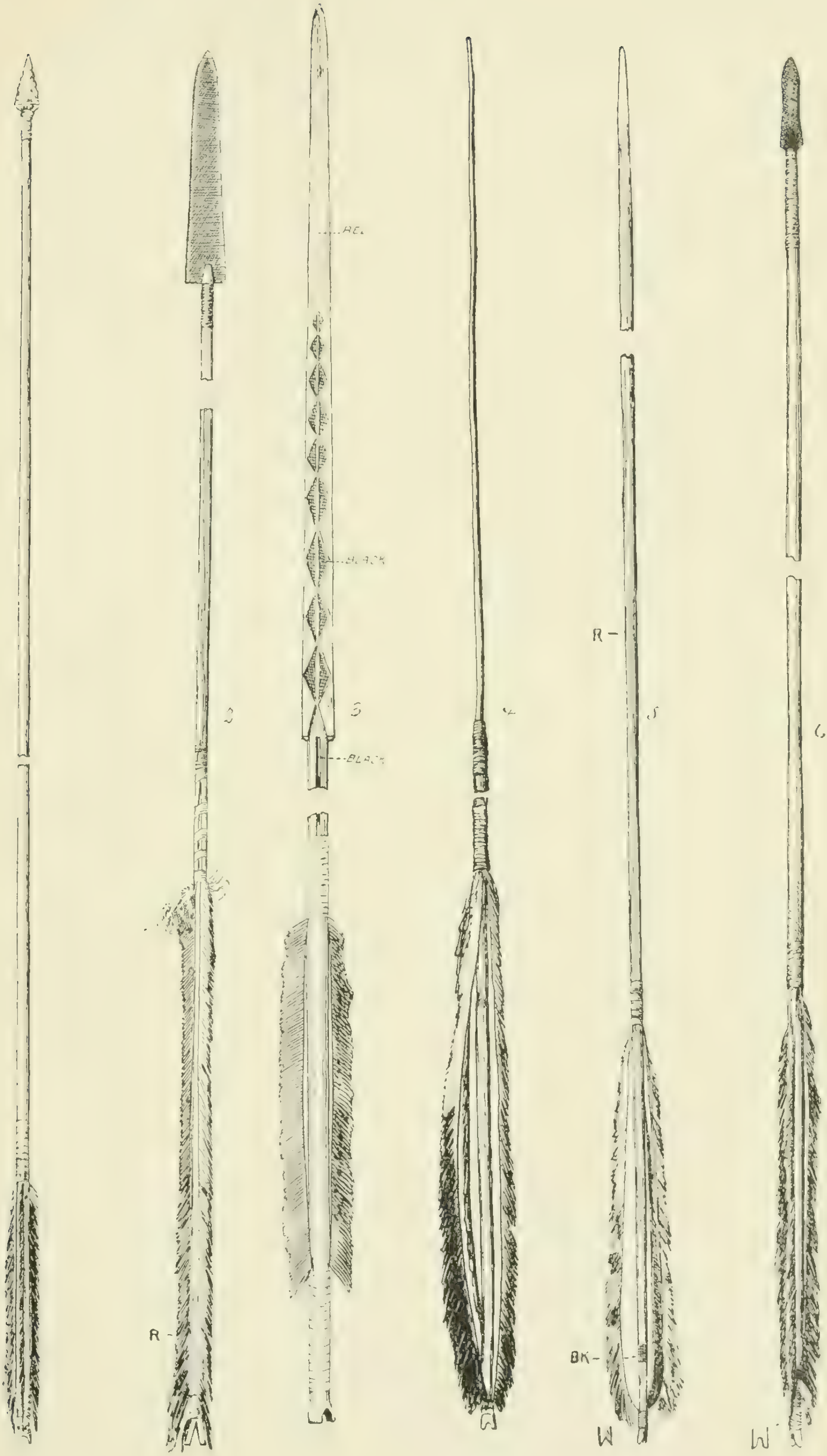
Cat. No. 1496, U. S. N. M.

FIG. 5. SHAFT, of rhus. Feathers, three, seized with sinew. Nock, cylindrical; notch, angular. There is no head. Length, 23½ inches.

Cat. No. 22287, U. S. N. M. Bannock Indians, Idaho. Collected by W. H. Danilson.

FIG. 6. SHAFT, of osier. Blood streaks, slightly wavy. Feathers, three, seized with sinew. It is difficult to say whether they were formerly glued to the shaftment or not. Shaftment, cylindrical. Notch, angular. Head of iron inserted into the end of the shaft and seized with sinew. In other specimens from the same tribe stone heads are found fastened on with a diagonal lashing of sinew. Total length, 26 inches.

Cat. No. 9048, U. S. N. M. Snake Indians, Idaho. Collected by Dr. C. Moffat.



ARROWS FROM VARIOUS TRIBES OF THE GREAT INTERIOR BASIN.

EXPLANATION OF PLATE XLV.

ARROWS OF CADDOAN TRIBES, TEXAS AND NORTHWARD.

FIG. 1. A simple rod or twig from which the arrow shaft is made. It was collected from one of the Indian tribes in the buffalo-hunting regions, and might have been the groundwork of any of the arrows upon this and the preceding plate.

FIG. 2. THE SHAFT of this arrow is a twig of osier; the shaft streaks two, straight. The shaftment is banded with blue, green, red, and yellow. Feathers three, laid on flat and seized with sinew at the ends. The edges are shorn, so as to give the arrows a neat appearance. The nock is spreading; notch, angular. Head, leaf-shaped, of hoop iron, inserted into a deep notch at the end of the shaft and seized with sinew. Total length of shaft, 27½ inches.

Cat. No. 8461, U. S. N. M. Tonkawa Indians, Texas. Collected by Dr. McElderry, U. S. Army.

FIG. 3. SHAFT, a slender rod of hard wood. Feathers, three, held in place by seizing with sinew and trimmed straight on the edge. Nock expanding and blood streaks straight and zigzag. Length, 2 feet 1 inch.

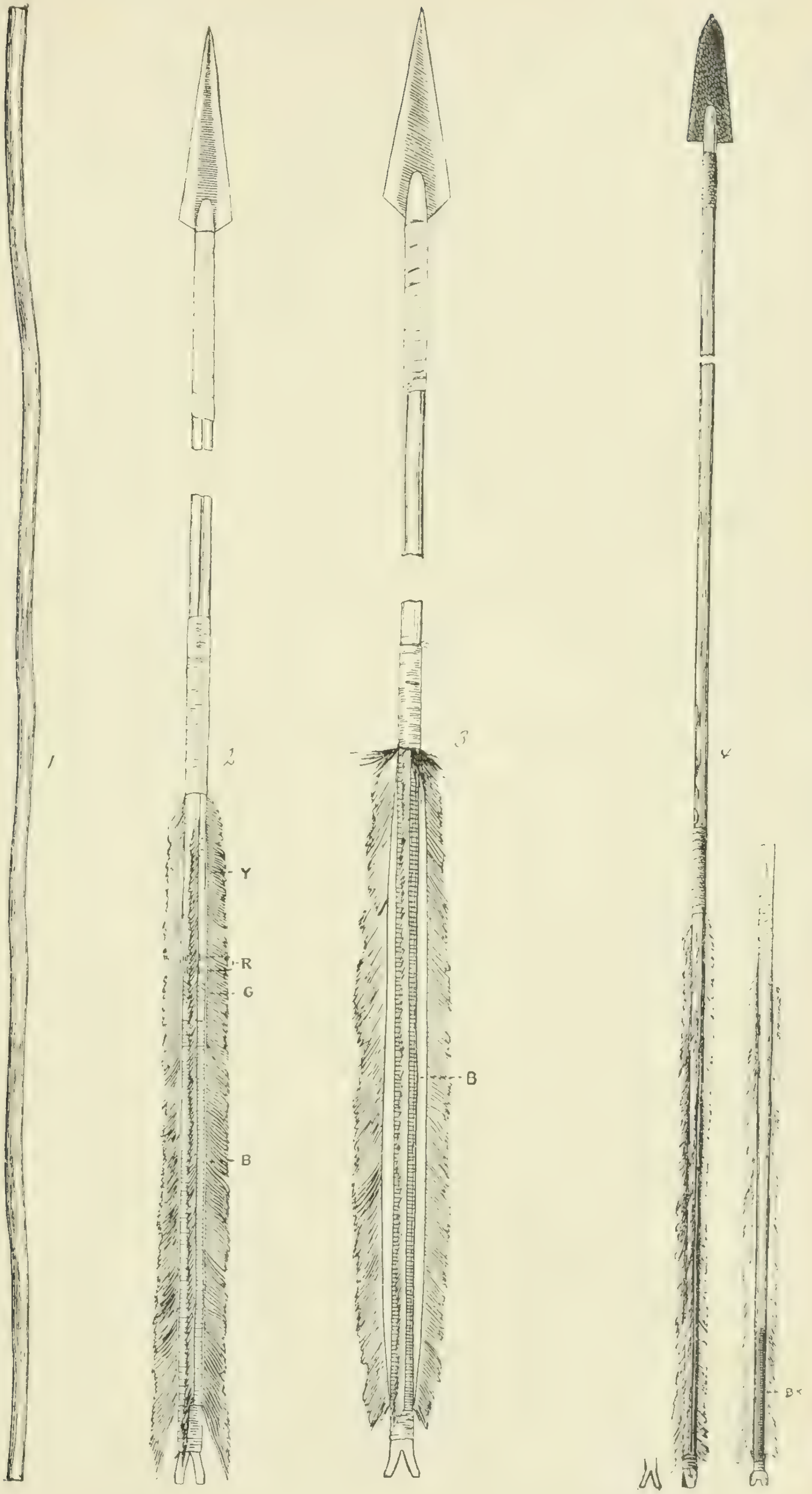
Cat. No. 6965, U. S. N. M. Wichita Indians, Caddoan stock. Collected by E. Palmer.

FIG. 4. SHAFT, of hard wood; head let into the end of the shaft and seized with sinew. Feathers, three, long, and glued down and seized smoothly at the ends with sinew. Nock, fish-tail. Shaft streaks, three in number, deep and sinuous. Length of shaft, 2 feet 1 inch.

Cat. No. 130795, U. S. N. M. Pawnee Indians, Caddoan stock, Nebraska. Collected by E. F. Bernard.

FIG. 5. SHAFT, a delicate twig, with blood streaks consisting of wavy furrows. Feathers, three, seized down with sinew and glued to the shaftment. Edges trimmed so as to form parallel lines. The front of the shaftment is ornamented with broad green bands. The shaftment is trimmed away at its extremity so as to leave the nock a cylindrical bulb. The notch is U-shaped. The head is a blade of iron inserted into a "saw cut" at the end of the shaft. The tang is serrated along the barb, securing the more effectual fastening of the head. Total length of shaft, 25 inches.

Cat. No. 129873, U. S. N. M. Pawnee Indians. Collected by H. M. Creel.



ARROWS OF CADDOAN TRIBES, TEXAS AND NORTHWARD.

EXPLANATION OF PLATE XLVI.

SIOUAN ARROWS, DAKOTA TRIBES.

FIG. 1. SHAFT, of osier. Shaftment, banded with red. Feathers, three, seized with sinew at the end and shorn neatly on the outer edges. Near the nock of the arrow is an ornamental feather in the feathering, produced by leaving the plume on both sides of the rib of the feather for about an inch, so that the arrow at this point appears to have six feathers. The nock is slightly spreading; notch, U-shaped. No head. Total length of shaft, 27¾ inches.

Cat. No. 21286, U. S. N. M. Sioux Indians, Minnesota. Collected by Rev. Geo. Ainslie.

FIG. 2. On this arrow a pyramidal piece of bone serves for a head, and the shaftment is striped with blue and red. This specimen is figured for the purpose of showing oddities of form since the adoption of the rifle. Neither of these arrows, probably, was ever used. Among the Plains Indians the iron arrowhead was introduced many years ago, and samples with stone heads are extremely rare and quite open to suspicion. Length, 24 inches.

Cat. No. 8439, U. S. N. M. Sioux Indians, Fort Berthold. Collected by Drs. Gray and Matthews, U. S. Army.

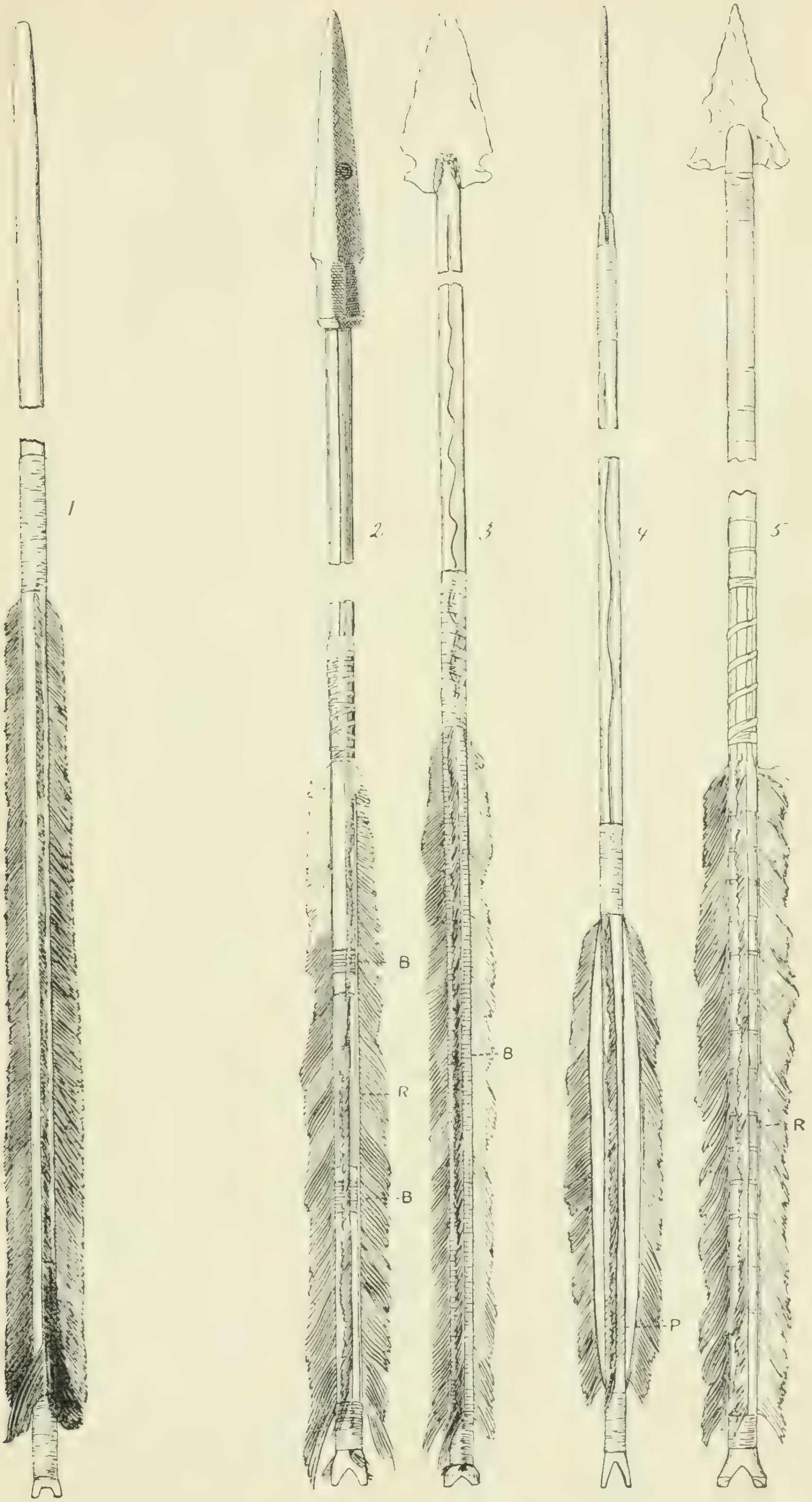
FIG. 3. SHAFT, a rod of osier; blood streaks, very jagged. Feathers, three, seized with sinew, loosely wrapped, glued to the shaftment, and there are streaks of blue paint drawn between the featherings. The nock is bulbous; the notch is widely angular. Head, of chalcedony, notched on the sides and glued into a notch in the end of the shaft. The seizing is gone from this arrow, but the notches in the side of the head, as well as the clean appearance of the shaft, indicate that it was once present.

FIG. 4. SHAFTMENT, a delicate rod of osier; blood streaks, wavy. Shaftment tapering toward the nock. Feathers, three, seized at the end with sinew and standing off from the shaftment. Nock, slightly expanding; notch, swallowtail-shaped. Head, a piece of wire driven into the end of the shaft, very neatly seized with sinew, and sharpened at the point. Length, 26 inches.

Cat. No. 2466, U. S. N. M. Sioux Indians. Collected by Dr. Washington Matthews, U. S. Army.

FIG. 5. SHAFT, of osier. Shaftment, banded with red. Feathers, three, seized at each end with sinew and glued. The nock is swallowtail-shaped; notch, angular. In the arrows of the Sioux the nock is usually very much widened out at the extremity, giving the warrior a firm grip in releasing. Head, of obsidian, rudely chipped and inserted into the notch in the end of the shaft. In the companion to this arrow the blood streaks are slightly jagged. The head is of white jasper and the feather is 10½ inches long. Length, 24 inches. Length of feathers, 10 inches.

Cat. No. 8439. U. S. N. M. Sioux Indians. Collected by Gray and Matthews, U. S. Army.



SIOUAN ARROWS, DAKOTA TRIBES.

EXPLANATION OF PLATE XLVII.

SIOUAN ARROWS, NEBRASKA AND DAKOTA.

FIG. 1. SHAFT, of osier. The shaftment is decorated with alternate bands of red, blue, and yellow. The shaftment is cut away at the outer end so as to leave the nock a projecting cylinder and give a better grip to the fingers in discharging the arrow. Notch, U-shaped. The head, a slender blade of iron let into a "saw cut" in the end of the shaft, the two lips of this cut being shaved down neatly so as to form no impediment to the progress of the arrow. This is a very delicate and effective weapon. The iron blade is slightly barbed at the base. Length of shaft, 26 inches.

Cat. No. 76831, U. S. N. M. Sioux Indians, Nebraska. Collected by Governor Furness.

FIG. 2. SHAFT, of hard wood. Shaftment ornamented with yellow and red bands. Feathers, seized with sinew, held on spirally, and glued to the shaftment. It is difficult to say whether this spiral arrangement was designed to make the arrow spin through the air. Authorities differ on this point, and the object of direct flight at close range would be more than canceled by the disadvantage of untangling a revolving arrowhead in the hair of the buffalo or deer. The nock is bulbous; notch, angular. Head, a diamond-shaped blade of sheet iron, inserted into the end of the shaft, and seized with sinew. Length of feathers, 7½ inches; total length of shaft, 26 inches.

Cat. No. 131356, U. S. N. M. Collected by Mrs. A. C. Jackson.

FIG. 3. SHAFT, of hard wood; point of iron, long triangle, inserted into the saw cut in the head and seized with sinew. Feathers, three, glued on, seized at the ends with sinew and trimmed down. The shaftment is ornamented with a blue band. The nock is fish-tail pattern. Shaft streaks sinuous. Other arrows from this same tribe have different colored bands in the shaftment. Length of shaft, 2 feet 3 inches.

Cat. No. 8418, U. S. N. M. Gros Ventres, Siouan stock. Collected by Dr. Matthews, U. S. Army.

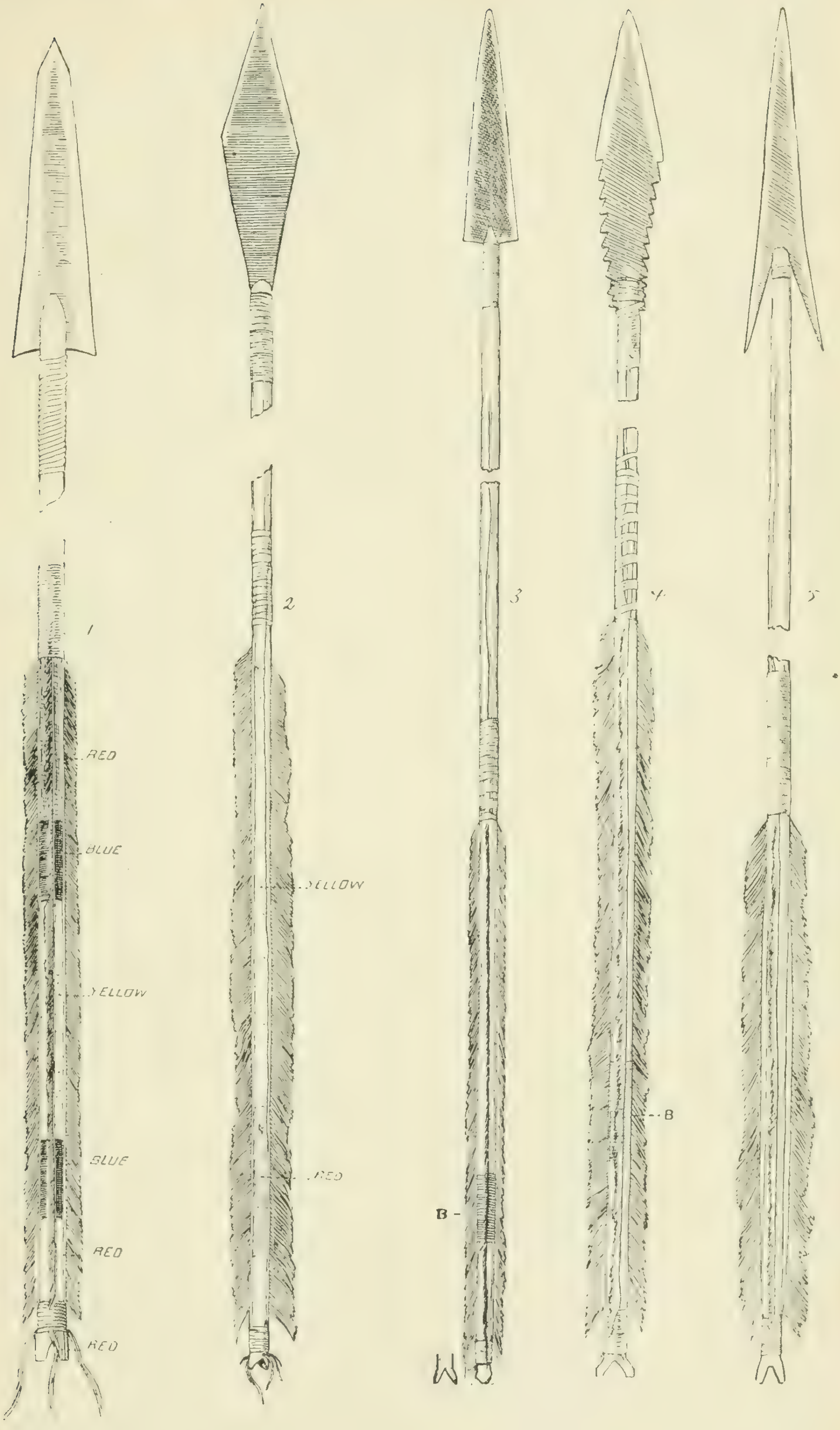
FIG. 4. Blood streaks, quite straight. Feathers, three, glued to the shaft, and seized with sinew. The strips of sinew with which the Sioux Indians lash their featherings are much broader than those used by the West Coast Indians, and very often are laid on like an open spiral or coil. The feathers are shorn. Nock, spreading; notch, shallow. Head, diamond-shaped, the margins of the inner half being filed like a saw. The head is inserted in the end of the shaft and seized with sinew. Total length of shaft, 25 inches.

Cat. No. 23736, U. S. N. M. Sioux Indians, Devil's Lake. Collected by Paul Beckwith.

FIG. 5. Example of arrows from the Sioux Indians by the U. S. Weather Bureau. This large number of arrows promiscuously gathered affords an excellent opportunity for studying the lines within which the bands and tribes of the same family vary their arrows. The shafts are all slender, made of hard wood. Some have shaft streaks, others none. They vary also in the number of streaks on the shaft and their form, whether straight, sinuous, or zigzag. These arrows differ also in the length and form of the points, in the length, attachment, and ornamentation of the feather, but all have the wide fish-tail nock, and this seems to be an unvarying quality in Sioux arrows.

Cat. No. 154016, U. S. N. M. Sioux Indians, Siouan stock. Collected by M. M. Hazen.

PLATE XLVII.



SIOUAN ARROWS, NEBRASKA AND DAKOTA.

EXPLANATION OF PLATE XLVIII.

ARROWS OF NORTHERN CALIFORNIA AND OREGON

FIG. 1. SHAFT, beautifully smoothed. Shaftment painted deep red. Feathers, three, glued on, and delicately seized at either end with sinew. The ends of the feathers project at least an inch beyond the notch. The nock is cylindrical; notch, U-shaped. Head, of obsidian, leaf-shaped, with notches near the base, let into a notch at the end of the shaft, seized with sinew and transparent glue. Total length of shaft, 31½ inches.

Cat. No. 2807, U. S. N. M. Oregon Indians. Collected by Lieut. Wilkes, U. S. Navy.

FIG. 2. SHAFT, of rhus. Shaftment, striped with black, red, and brown. Feathers, seized at the end with sinew, standing off from the shaftment, and shorn quite close to the midrib. Nock, cylindrical; notch, U-shaped. Foreshaft, of hard wood, painted red, sharpened, inserted into the end of the shaft, and seized with sinew. Head, an extremely delicate point of obsidian, triangular, inserted into a notch in the end of the shaft, and seized with sinew diagonally laid on notches on the sides of the arrowhead. Total length of shaft, 30 inches.

Cat. No. 15127, U. S. N. M. Northern California. Collected by Wm. Rich.

FIG. 3. SHAFT, a slender twig of rhus, striped with red and blue at its upper extremity. The shaftment is ornamented with zigzag lines in the same colors. Feathers, three, glued to the shaftment and seized at either end with sinew. Nock, cylindrical; notch, very slight. Head, of obsidian, slender, sagittate in form; the tang inserted in a slit at the extremity of the shaft and seized with sinew. This shaft has a barb of very narrow regular grooves around the upper extremity, as though produced by a lathe. This feature is common to many California arrows. Total length of shaft, 29 inches.

Cat. No. 126517, U. S. N. M. Hupa Indians, California. Collected by Capt. P. H. Ray, U. S. Army.

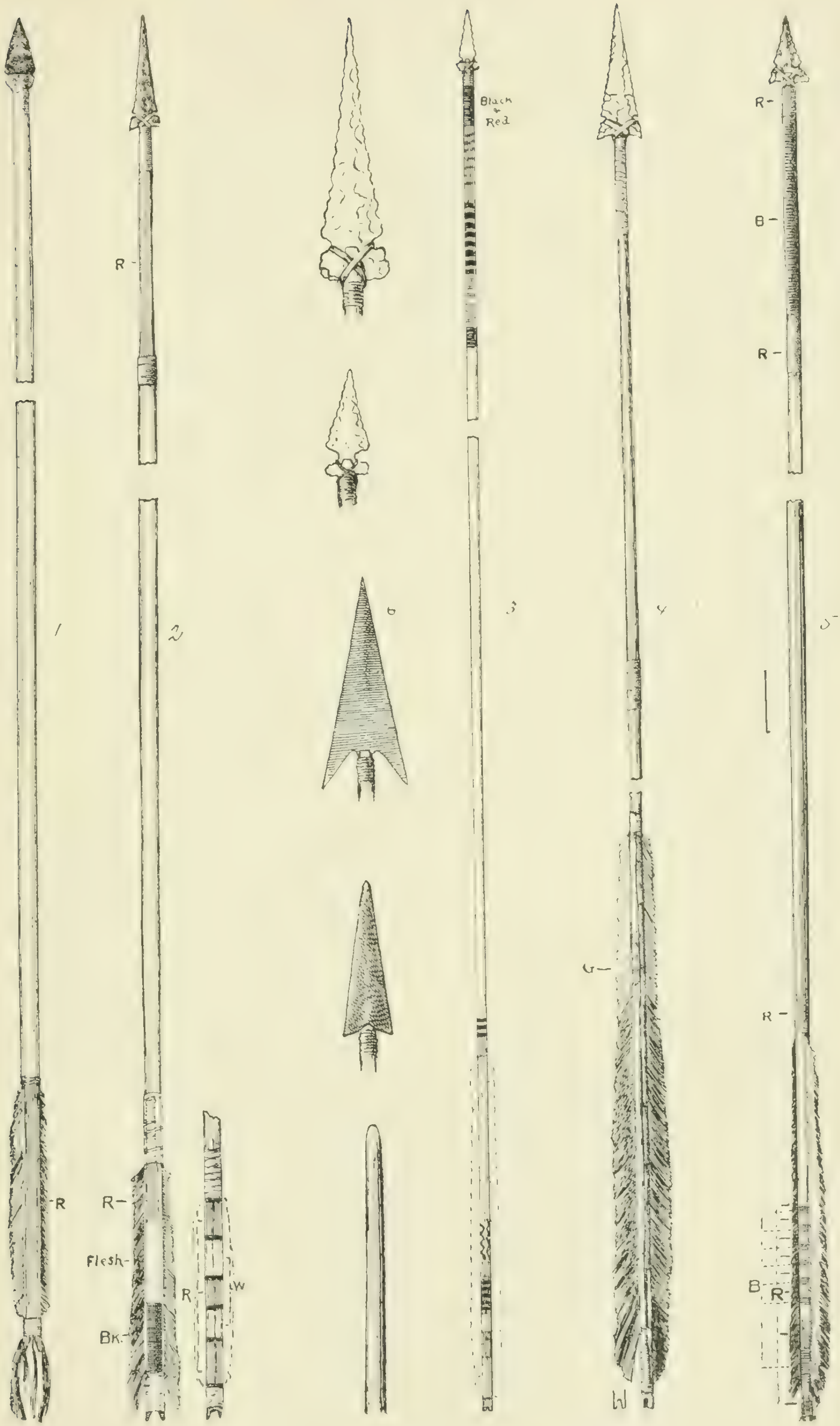
FIG. 4. SHAFT, a rod. Shaftment, striped with green. Feathers, three, seized at the ends with sinew and laid flat on the shaftment. Nock, cylindrical; notch, U-shaped. Head, of gray chert, long, and delicately inserted in the end of the shaft by a seizing which passes around the deep notches at the sides. Total length, 34 inches. The shafts of the California arrows are of wild currant, rhus, willow, and other straight twig-like stalks.

Cat. No. 131110, U. S. N. M. Pitt Indians, California. Collected by N. J. Purcell.

FIG. 5. SHAFT, a rod; striped with narrow bands of blue and red and the natural color of the wood. Feathers, three, neatly shorn, seized with sinew and glued fast to the shaftment. The sinew is colored with a red paint resembling shellac. Nock, cylindrical; notch, shallow. Foreshaft, of hard wood, painted blue, inserted in the end of the shaft and seized with sinew. In many of the California arrows the foreshafts have been revolved between two coarse pieces of sandstone, or by means of a file cut so as to give the appearance of being neatly seized with very fine thread. It also confers a suspicion of machinery on some of these later examples. The head is of jasper, triangular, delicate, tapering, deeply notched on the side, and held in place by a diagonal lashing of sinew. Other specimens from the same quiver have heads of chalcedony, the edges of which are beautifully serrated. Total length, 31 inches.

Cat. No. 126517, U. S. N. M. Hupa Indians, California. Collected by P. H. Ray.

FIG. 6. This figure shows the variety of arrow points in use among the Indians of Upper California. Glass, obsidian, steel, iron points, and wooden foreshaft sharpened, together with others in the same plate, give an understanding of the various ways of attaching the arrowhead to the shaft and foreshaft.



ARROWS OF NORTHERN CALIFORNIA AND OREGON.

EXPLANATION OF PLATE XLIX.

ARROWS OF PACIFIC STATES, FROM CALIFORNIA TO WASHINGTON.

FIG. 1. THE SHAFT is spindle-shaped, tapering to the nock. Feathers, two, held on flat and seized with pack thread. Nock, expanding; notch, angular. Head, a bit of iron wire, inserted in the end of the shaft, which has been pointed for the purpose, and expanded at the end into a leaf-shaped blade. In some samples the barbs have been cut into this leaf shape partly by means of a filing, to enable the hunter to retrieve his game the better. The total length of the shaft is 28 inches.

Cat. No. 127872, U. S. N. M. Quinaielt Indians, State of Washington. Collected by C. Willoughby.

FIG. 2. Similar to fig. 1 in every respect, excepting the point. There are endless varieties in these.

FIG. 3. STEM, a single rod or twig. Point of brown bottle glass inserted into a notch in the end of the shaft and held in place by a broad band of sinew. Feathers, three, seized at the end with sinew. Shaftment painted red. The notch similar to those of the Chinese arrows. Length of arrow, 31¾ inches.

Cat. No. 76021, U. S. N. M. Tribe unknown, probably Central California.

FIG. 4. SHAFT, of spruce. Feathers, three, seized with sinew. Nock, cylindrical; notch, angular. The point is a slender spindle of hard wood inserted into the end of the shaft, seized with sinew, and sharpened at the point. This is a very delicate and effective weapon. Total length, 25 inches.

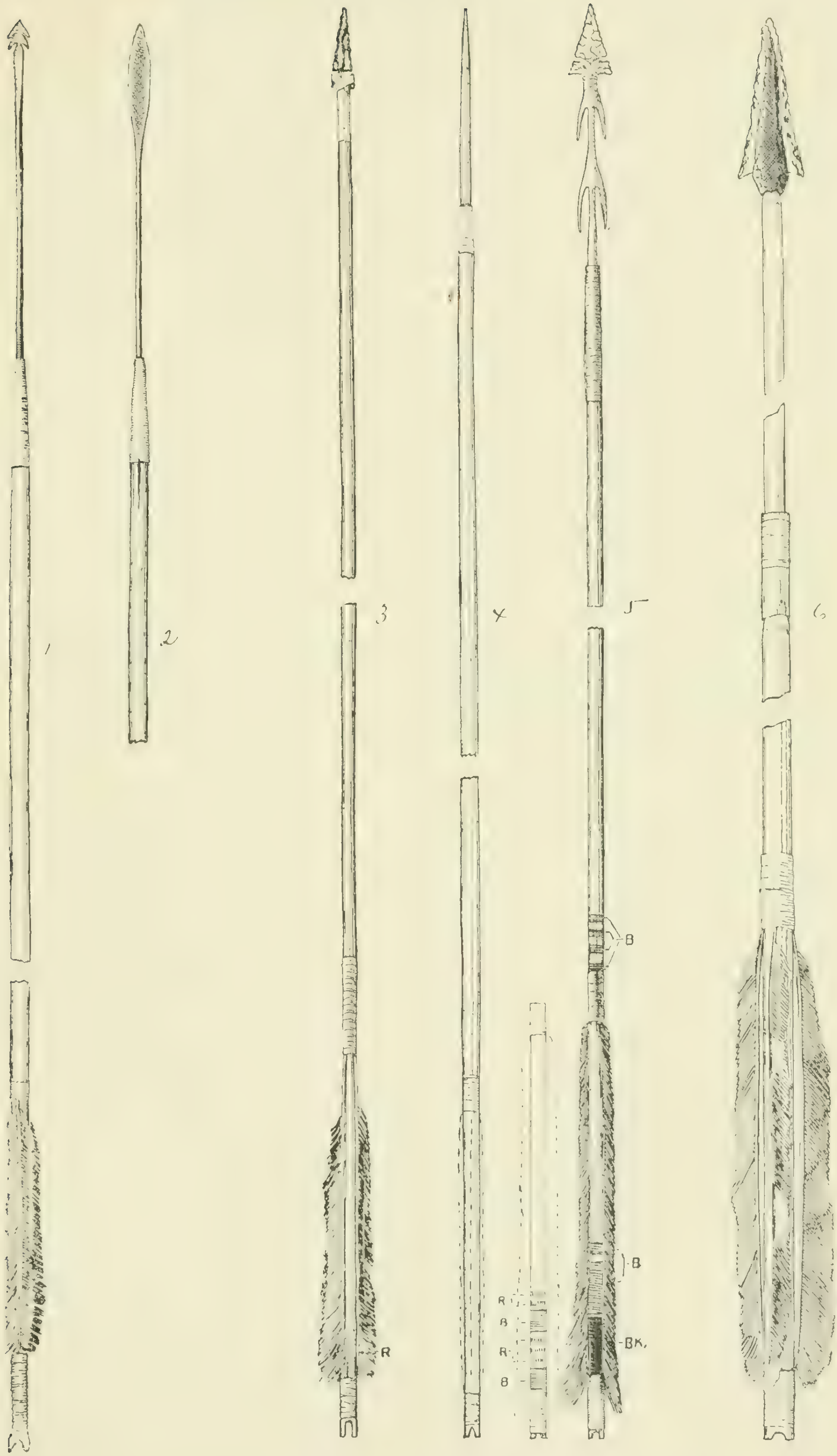
Cat. No. 649, U. S. N. M. Klamath Indians, California. Collected by George Gibbs.

FIG. 5. SHAFT, of twig. Shaftment striped with narrow bands of red and blue. Feathers, three, glued to the shaftment. Nock, cylindrical; notch, very shallow. The head consists of a stone blade and a barb piece of bone. The barb piece is inserted in the end of the shaft and seized with sinew. The barbs are ¾ of an inch long. The stone blade, of red jasper, is fastened to the bone barb piece by a diagonal lashing of sinew. This device is for the purpose of retrieving. If shot into a fish it enables the hunter to secure the animal and free the arrow. If shot at a burrowing animal and the creature escapes into its hole the hunter has a means of recovering the game. Total length of shaft, 30 inches. The adjoining figure on the left is of the same type with different ribbon.

Cat. Nos. 21353, 126576, U. S. N. M. Uroc Indians. Collected by Stephen Powers.

FIG. 6. SHAFT, of reed. Shaftment painted white. Feathers, three, 4¾ inches long, seized with sinew. The notch, a shallow cut. Foreshaft, of hard wood. Head, of obsidian, let into the end of the foreshaft and neatly fastened with gum, which is molded to conform to the lines of the arrowhead and to impede as little as possible its flight. This arrow is very neatly made. Length of shaft, 33 inches.

Cat. No. 19709, U. S. N. M. Indians, of Tule River, California. Collected by Stephen Powers.



ARROWS OF PACIFIC STATES, FROM CALIFORNIA TO WASHINGTON.

EXPLANATION OF PLATE L.

ARROWS OF TRIBES ABOUT PUGET SOUND, WASHINGTON, AND BRITISH COLUMBIA.

FIG. 1. SHAFT, of cedar. No feathers. Head, a triangular piece of hoop iron inserted into the end of the shaft and seized with twisted sinew. The shaft is ornamented with a spiral band of black. Length of shaft, 32½ inches.

Cat. No. 650, U. S. N. M. Makah Indians, Cape Flattery. Collected by J. G. Swan.

FIG. 2. SHAFT, of spruce. Head, of iron, inserted into split end of the shaft. Seized with sinew cord. Feathers, three, lashed on with sinew thread. Nock, expanding. Length of arrow, 30 inches.

Cat. No. 650, U. S. N. M. Makah Indians, Cape Flattery. Collected by George. Gibbs.

FIG. 3. SHAFT, of cedar, tapering both ways from the middle. Seized at the front end with birch bark. Into this end is driven one or more barbed points, of brass or iron wire, pounded flat at the point. One or two barbs filed upon the edges. Feathers, two, laid on flat and seized in place by spruce or birch bark. The nock expands gradually from the feather to the end, where it is spread conspicuously. The noticeable features of this arrow are the following: First, the barbed metallic points taking the place of the ancient bone barbs of Wilkes's time; second, the seizing by means of narrow ribbons of spruce or birch bark; third, the feathers laid on flat, after the fashion of the Eskimo; fourth, exaggerated widening of the butt of the arrow at the nock. There are many specimens of this type in the National Museum. Length: shaft, 2 feet 11 inches; foreshaft, 6½ inches.

Cat. No. 72656, U. S. N. M. Makah Indians, Wakashan stock, Washington. Collected by J. G. Swan.

FIG. 4. Similar to fig. 3, with difference in shape of metal point.

FIG. 5. SHAFT, spindle-shaped. Feathers, two, laid flat, after the manner of the Eskimo, and seized with narrow strips of bark. Nock, angular, long; ornamented with a wrapping of red flannel, the end of the feather being at least two inches from the end of the arrow. It widens out very rapidly toward the end. Notch, angular. The point, a long spindle of bone with its shallow barbs on one side inserted in a cavity at the end of the shaft and neatly seized with bark. Total length of shaft, 28 inches.

Cat. No. 76295, U. S. N. M. Makah Indians, Wakashan stock. Collected by J. G. Swan.

FIG. 6. SHAFT, of cedar. Feathers, three, 10 inches long, closely shorn, seized with strips of bark and a bird's feather nicely laid on. The shaft of the arrow is thickest in the middle and tapers in both directions toward the nock where it is smallest, widening out toward the end. Nock, angular. Two points of wood are fastened to the end of the shaft with a neat seizing of bark. In this sample one point is much longer than in the other and the barbs are on the outside. Length, 30 inches.

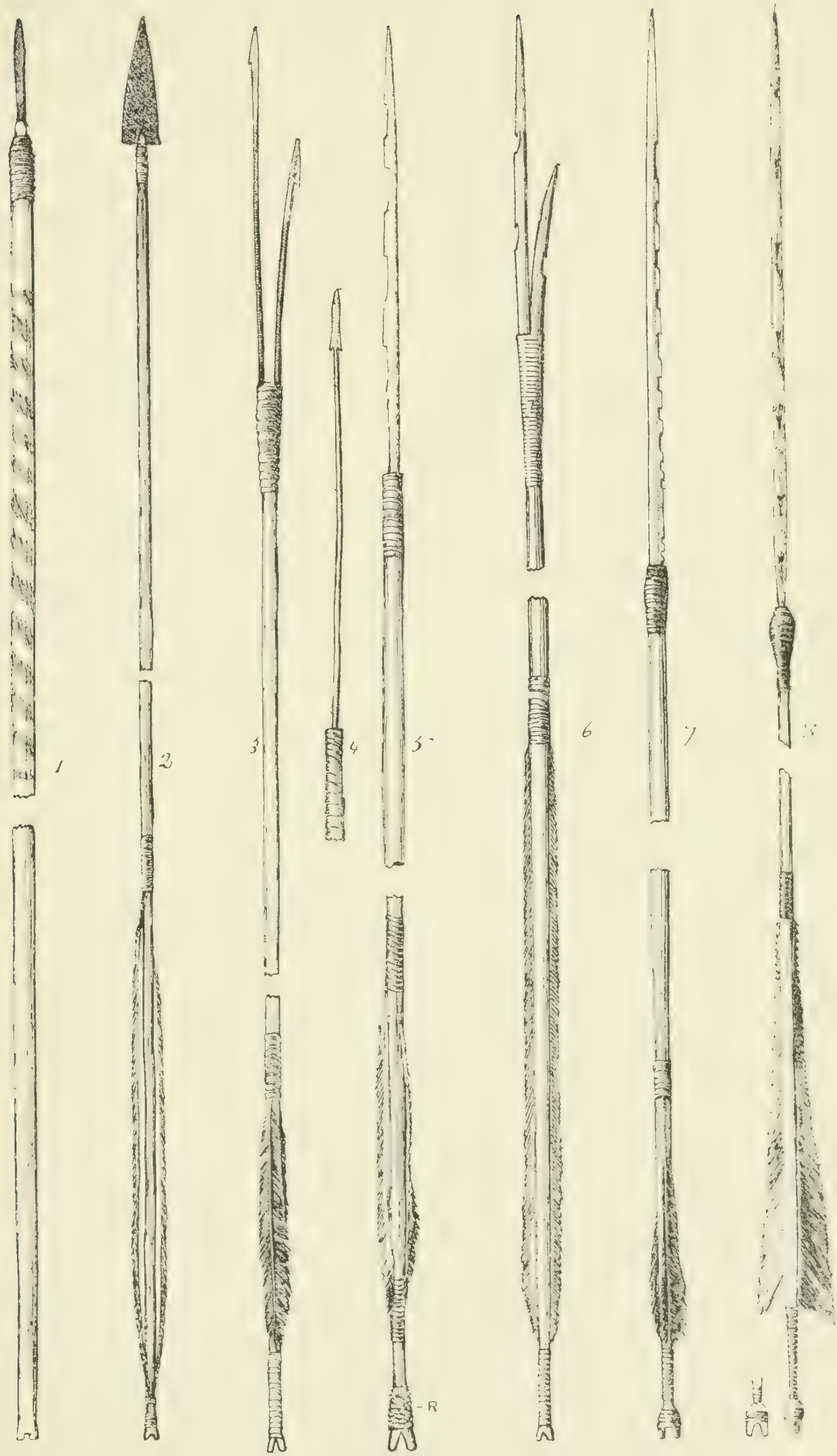
FIG. 7. SHAFT, similar to that of fig. 6, but there is a single point of bone with barbs on one side. Feathers, two, laid on flat at their ends. Feathering and nock have a separate seizing of bark. Length, 27 inches.

Other samples in the same quiver are quite similar in characteristics, with variations in the barbs.

Cat. No. 2790, U. S. N. M. State of Washington. Collected by Capt. Charles Wilkes.

FIG. 8. Quite similar to fig. 6 in general form, but the two feathers are laid on flat and spirally. The nock, however, is much ruder, and the point is a long delicate piece of bone, with small barbs on both sides, inserted into the split end of the shaft and seized with bark. Length, 32½ inches.

Cat. No. 2787, U. S. N. M. Columbia River, Oreg. Collected by Capt. Charles Wilkes.



ARROWS OF TRIBES ABOUT PUGET SOUND, WASHINGTON AND BRITISH COLUMBIA.

EXPLANATION OF PLATE LI.

ARROWS OF SOUTHEASTERN ALASKA AND WESTERN BRITISH COLUMBIA.

FIGS. 1 and 2. Four examples of Tlingit arrowheads, three of them with barbed pieces to which the metal heads are riveted. These arrowheads have two functions—that of retrieving the game and that of parting easily from the shaft and rankling in the victim until it dies. These should be compared carefully with stone heads in Old World specimes having very long barbs

FIG. 3. All in one piece; which widens out into a large cone to form a head; slightly expanding at the nock. The notch is formed by cutting off the end of the arrow into an expanding wedge and then making a very shallow incision across the edge. Painted brown and streaked with red. Length, 38 inches.

Cat. No. 63551, U. S. N. M. Sitka, Alaska. Collected by J. J. McLean.

FIG. 4. SHAFT, of cedar, tapering in two directions. The head is formed of a piece of wire sharpened at one end and driven into the shaft. The other end is flattened and filed to a barb on one side. Similar to fig. 4, Pl. L.

Cat. No. 73547, U. S. N. M. Haidas, Queen Charlotte Islands. Collected by J. G. Swan.

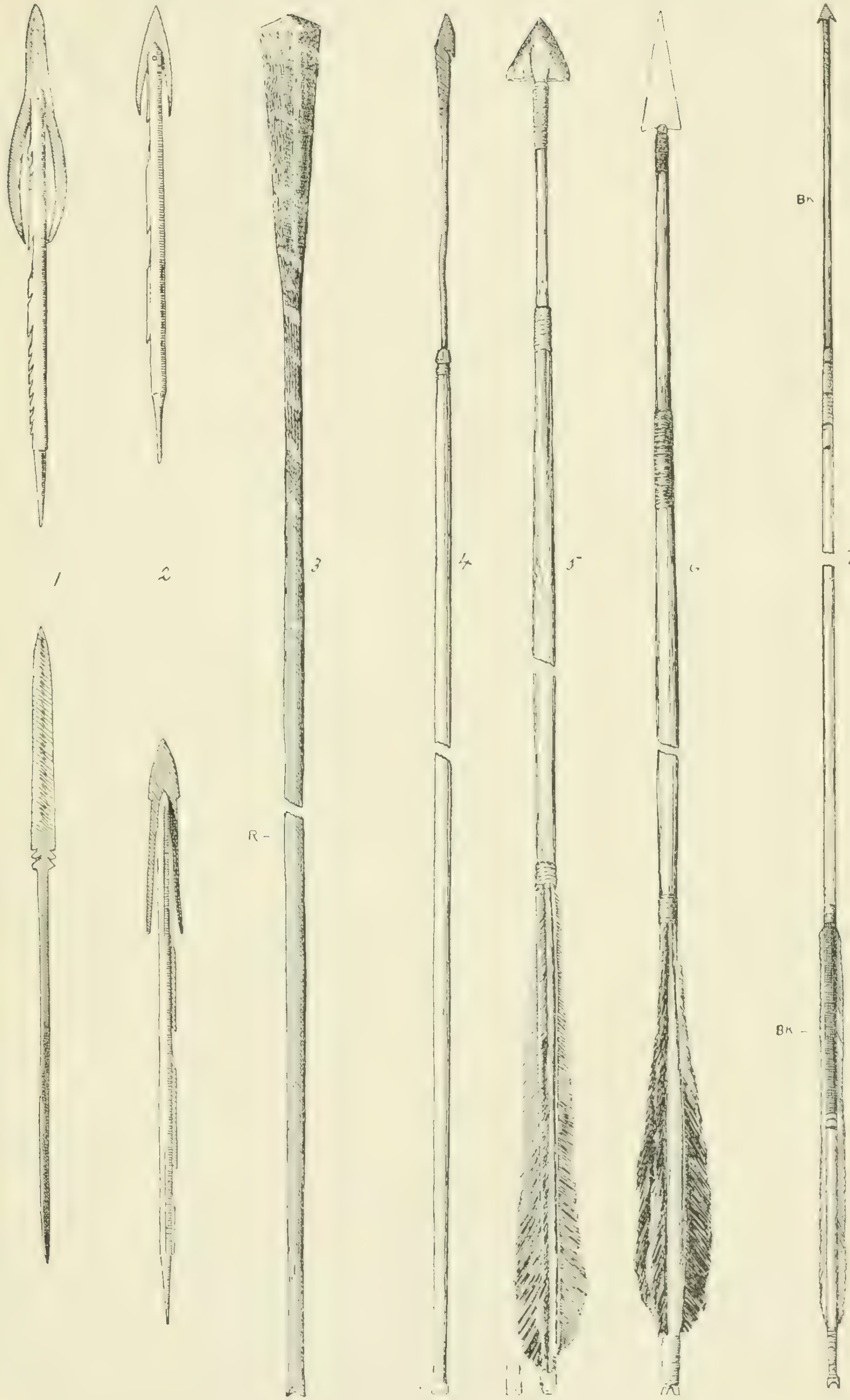
FIG. 5. Similar to fig. 6, excepting the point is of shell.

FIG. 6. SHAFT, of cedar. Foreshaft let in with a wedge-shaped dowel. Head, a thin sheet of bone, sagittate. Feathers, three, fastened at the ends with sinew covered with glue. Nock somewhat flat, as in the Eskimo arrow. The noticeable features of this arrow are the thin head of bone, the foreshaft, let into the shaft and the flattening nock. Length of shaft, 21 inches; foreshaft, 6 inches.

Cat. No. 20694, U. S. N. M. Bella Coola Indians, Salishan stock, B. C. Collected by J. G. Swan.

FIG. 7. SHAFT, of cedar, tapering both ways from the middle. Shaftment painted black. Feathers, three, seized at each end with sinew and glued fast to the shaftment. Nock, bulbous; notch, U-shaped. Foreshaft, of hard wood neatly doweled into the end of the cedar shaft, seized with sinew, and painted black. The head is a minutely-barbed thin blade of iron, inserted into the foreshaft and seized with sinew. These are the smallest metal arrow-heads found on any arrow in the world. This arrow was found in Mr. Catlin's collection, after his death, without the name of the tribe; but the wood and the delicate finish point to Oregon as its source. Total length, 32 inches.

Not numbered. Oregon. Collected by Mr. Catlin.



ARROWS OF SOUTHEASTERN ALASKA AND WESTERN BRITISH COLUMBIA.

EXPLANATION OF PLATE LII.

BARBED AND HARPOON ARROWS OF THE ESKIMO ABOUT THE ALASKAN PENINSULA.

FIG. 1. SHAFT, of cedar, 23½ inches long and ½ inch thick. A streak of red around the middle and either end. The shaftment is somewhat flat, and ornamented with two narrow streaks of red and one bright streak of blue. Feathers, three, two black and one banded brown and white; the ends inserted into slits cut in the shaft and seized with sinew poorly laid on. The middle portions of the feathers are not glued to the arrow. The nock is flat, in a plane with the head, and is simply notched. The barb piece of bone is 8 inches long and is let into a socket in end of arrow shaft. It has a strong barb on one side at right angles to the head. It is ornamented with deep longitudinal furrows. The triangular head of bone is a flat blade inserted neatly in a deep slit at the head of the barb piece, which is smoothed down so as to present no impediment to the passage into the animal struck.

Cat. No. 127627, U. S. N. M. Alaska. Collected by J. W. Johnson.

FIG. 2. SHAFT, of spruce, cylindrical; coarsely made; banded with red paint. Feathers, three, seized with sinew, one of them at the middle of the flat side and the other two at the round corners of the other side. As usual with the Eskimo, the end of these feathers is sunk into notches cut in the soft wood. The nock is flat; the notch, angular. There is a barb piece of bone set into the shaft, at the end, by a cylindrical tenon, and is seized with sinew. Blade, of iron, set into the barb piece at right angles to the plane of its longest diameter and cross section. One barb in the side of the barb piece. Total length, 28 inches.

Cat. No. 127627, U. S. N. M. Eskimo, Bristol Bay, Alaska. Collected by J. W. Johnson.

FIG. 3. SHAFT, of cedar, cylindrical. Shaftment, flat, banded with blue stripes. Feathers, three, seized with sinew thread and standing off quite a distance from the shaftment. The nock is flat; notch, angular. Blade, of slate, inserted into the end of the barb piece of bone. The single barb is 1¼ inches long and is formed on one side by a narrow notch. Two shallow gutters extend from this barb to the end of the shaft. The barb piece is fitted into the end of the shaft by a dowel or peg made of bone and lashed with a fine sinew thread. The blade is covered by a cap made of two pieces of cedar neatly cut for the blade and the end of the barb piece and joined together with a braid of sinew. This is a very effective and neatly-made weapon. Total length of shaft, 30 inches.

Cat. No. 90404, U. S. N. M. Kadiak, Alaska. Collected by Wm. J. Fisher.

FIG. 4. SHAFT, of cedar; about half an inch in diameter in the middle, tapering slightly forward to within two inches of the end, where it is cylindrical, and tapering backward gradually to the nock. Feathers, three, laid on at equal distances apart and seized with fine sinew thread. The plume of the feather is neatly cut into a triangular shape. The shaftment is painted red. The nock is a bulb of extraordinary size, which gives the hunter all the grip he could ask. Notch, shallow and angular. Foreshaft, of bone, let into the end of the shaft by a dowel cut on the end of the bone. A

small wooden plug is inserted into the front end of this and perforated. The head is a small triangular piece of bone, barbed on one side, cut away at the butt to form a very short dowel to be inserted into the perforation in the shaftment, and perforated near the base to receive a lanyard or martingale of braided sinew, which, near the other extremity, has two branches, one of which is attached to the front of the shaft and the other towards the butt end. This arrow operates in the following manner: When this line is unrolled it resembles a kite's tail—the bird to which the barb is attached representing the tail and the spreading bifurcation the point attached to the kite. This line is neatly rolled up on the shaft to the end of the foreshaft. The barbed head is then put in place; the line tucked under the coil and drawn tight, but not fastened. The hunter shoots the game with this arrow; the barb penetrates beneath the skin; the sudden movement of the sea otter withdraws the barb head from the foreshaft and loosens the slight fastening of the coil, which is then unrolled, and the bone head, being heavier, sinks in the water, while the light shaft supports the feather above the surface, the whole apparatus acting as a drag to the game and also as a buoy to enable the hunter to follow. Total length of shaft, 34¼ inches.

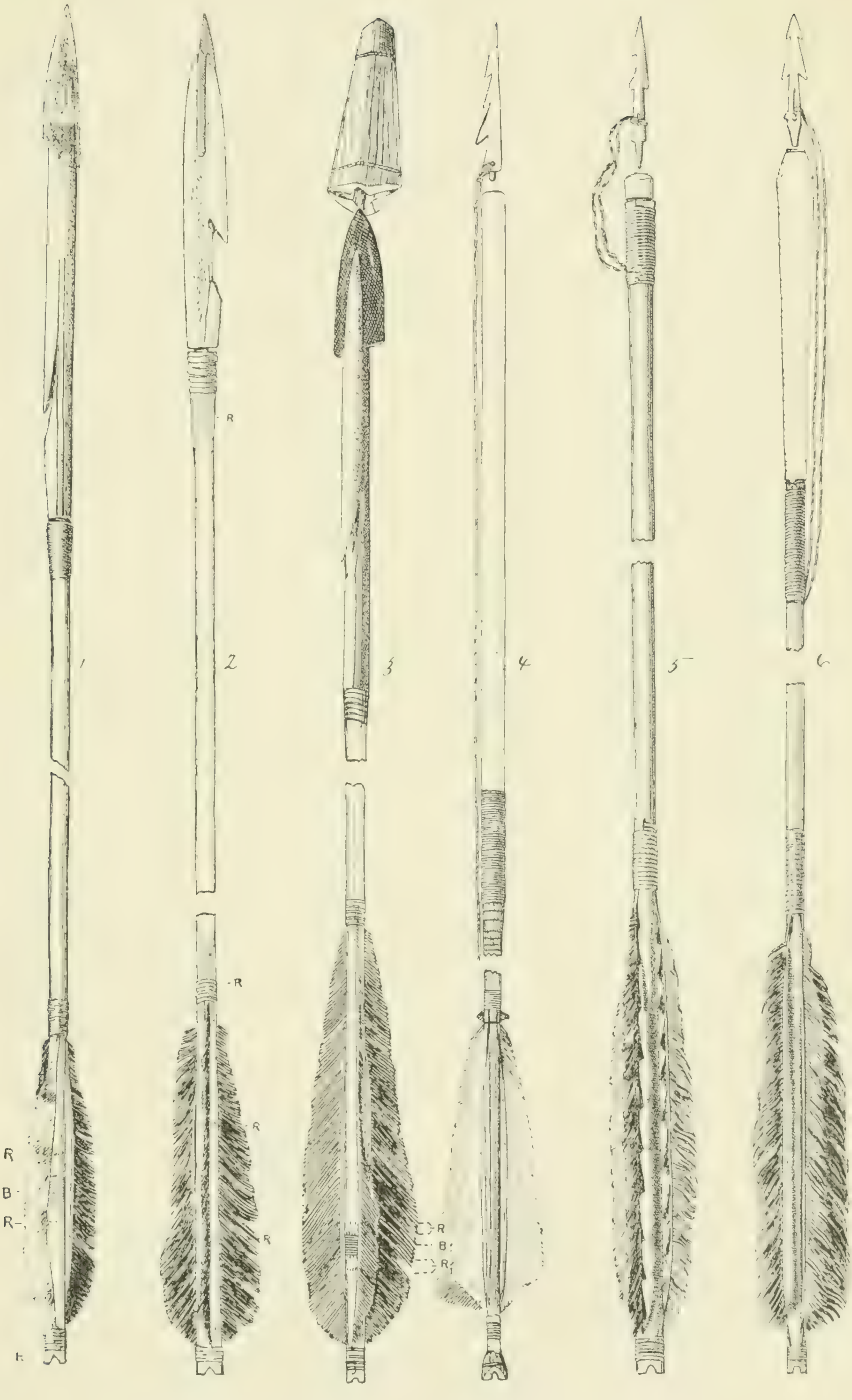
Cat. No. 16407, U. S. N. M. Kadiak, Alaska. Collected by W. H. Dall.

FIG. 5. SHAFT, of spruce, cylindrical. Shaftment, flattened. Three black feathers, seized with sinew. The nock is flat; notch, rectangular. The barbed head is leaf-shaped, with two small barbs on one side and one on the other. The head is fitted into the end of the shaft, which is seized with sinew. Length, 33½ inches.

Cat. No. 19382, U. S. N. M. Eskimo, Cook's Inlet, Alaska. Collected by Mr. Early.

FIG. 6. SHAFT, of spruce wood, cylindrical. Shaftment, flattened. Feathers, three, seized at one end with sinew and at the other with sinew thread. The feathers are laid on at the round corners of the flattened shaftment, so that really there could have been another feather at one of the corners. The nock is flat; the notch of the usual U shape. Foreshaft, of walrus ivory, one end cut into the shape of a tenon and inserted in the end of the shaft and seized with sinew thread. The front end of this shaft is perforated and into this is inserted a plug of soft wood. The delicate head has two barbs on either side, and a perforation through the body for holding a sinew cord, which attaches it to the shaft. The head is loosely fitted into the foreshaft by a conical tang. This weapon is shot from a bow into a sea otter or other game. The barbed head becomes fastened in the skin and withdraws from the foreshaft. The ivory head sinks in the water, leaving a feathered shaft bobbing in the air. The whole acts as a drag upon the game and also enables the hunter to follow. Length of shaft and foreshaft, 31¾ inches.

Cat. No. 72412, U. S. N. M. Eskimo, Bristol Bay. Collected by Charles McKay.



BARBED AND HARPOON ARROWS OF THE ESKIMO ABOUT THE ALASKAN PENINSULA.

EXPLANATION OF PLATE LIII.

ESKIMO ARROWS, WITH FLAT FEATHERS AND LONG POINTS.

FIG. 1. SHAFT, of spruce wood, tapering from the head backwards to a point, to which a single feather is fastened by a seizing of sinew. The point, of walrus ivory, inserted in a split in the end of the shaft, and seized with sinew. Other specimens of these darts are .eized with a fine rawhide line of babiche. Length of shaft and point, 19 inches.

Cat. No. 45476, U. S. N. M. Eskimo, Cape Nome, Alaska. Collected by E. W. Nelson.

FIG. 3. SHAFT, of pine, short and thick. Head, of bone; spatulate and spliced on to the shaft and held in place by sinew. In the specimens of this type made after contact with the whites the type of this spatulate point has a saw cut across the end, into which a blade of iron is inserted and held in place by a rivet. The connection between these two forms should be especially noted, as the more recent could not be explained without comparison with the ancient form. Length of shaft, 1 foot 5½ inches; foreshaft, 5 inches.

Cat. Nos. 34052–55, U. S. N. M. Eskimo of Cumberland Gulf. Collected by Ludwig Kumlien.

FIG. 2. Similar to fig. 3, except that the head is of iron.

FIG. 4. SHAFT, of spruce wood. Head, a flat blade of iron, widened at the point and inserted into the split end of the shaft and held in place by the lashing of babiche or rawhide string. Feathers, two, laid on flat, the ends inserted into the wood of the shaft. Nock, flat; notch, large and deep.

Not numbered. St. Lawrence Island Eskimo. Collected by E. W. Nelson.

FIG. 5. SHAFT, of spruce wood, spliced, owing to the scarcity of material. Two feathers, laid on flat and seized with sinew. Nock, flat; notch, angular. The point, a bit of iron from a whaling ship, flattened out and fastened into a slit at the end of the shaft by a seizing of sinew thread. The point has been hammered and filed coarsely into cylindrical shape, Total length of shaft, 17 inches.

Cat. No. 30016, U. S. N. M. Collected by W. A. Münster.

ESKIMO ARROWS WITH FLAT FEATHERS AND LONG POINTS.

EXPLANATION OF PLATE LIV.

Bird Bolts from various Areas.

Fig. 1. Shaft, cylindrical and flattened toward the notch. No feathers. Notch, with parallel sides. Head, a bullet-shaped piece of walrus ivory, perforated and fitted on the end of the shaft. Total length of shaft, 25 inches.

Not numbered, U. S. N. M. St. Lawrence Islands. Collected by E. W. Nelson.

Fig. 2. The shaft, cylindrical and flattened toward the nock. Feathers, two, on inner ends, securely inserted into gashes on the side of the shaft, and the outer extremity seized with sinew. Notch, shallow. Head, of bone or antler, blunt-shaped, like a flower bud, with seven nodes or projections around the margin. This style of arrow is very common in this region. The head is found in a great variety of shapes, but they are all used for the purpose of stunning birds without drawing blood. Total length, 27 inches.

Cat. No. 45432, U. S. N. M. Eskimo, Cape Darby, Alaska. Collected by E. W. Nelson.

Fig. 3. Shaft, of cedar; 25 inches long; narrow streak of red ocher around at upper extremity. Shaftment, flat; feather end near the nock without seizing; at the other extremity seized with sinew thread. Nock, flat; notch, very deep. The head is a cylinder of antler, hollowed at the lower extremity and fitted into the shaft with a conical tenon fitted into a cavity of the same shape. The head, at its upper extremity, is gashed, so as to have four pointed projections.

Cat. No. 33833, U. S. N. M. Eskimos of Pastolik. Collected by E. W. Nelson.

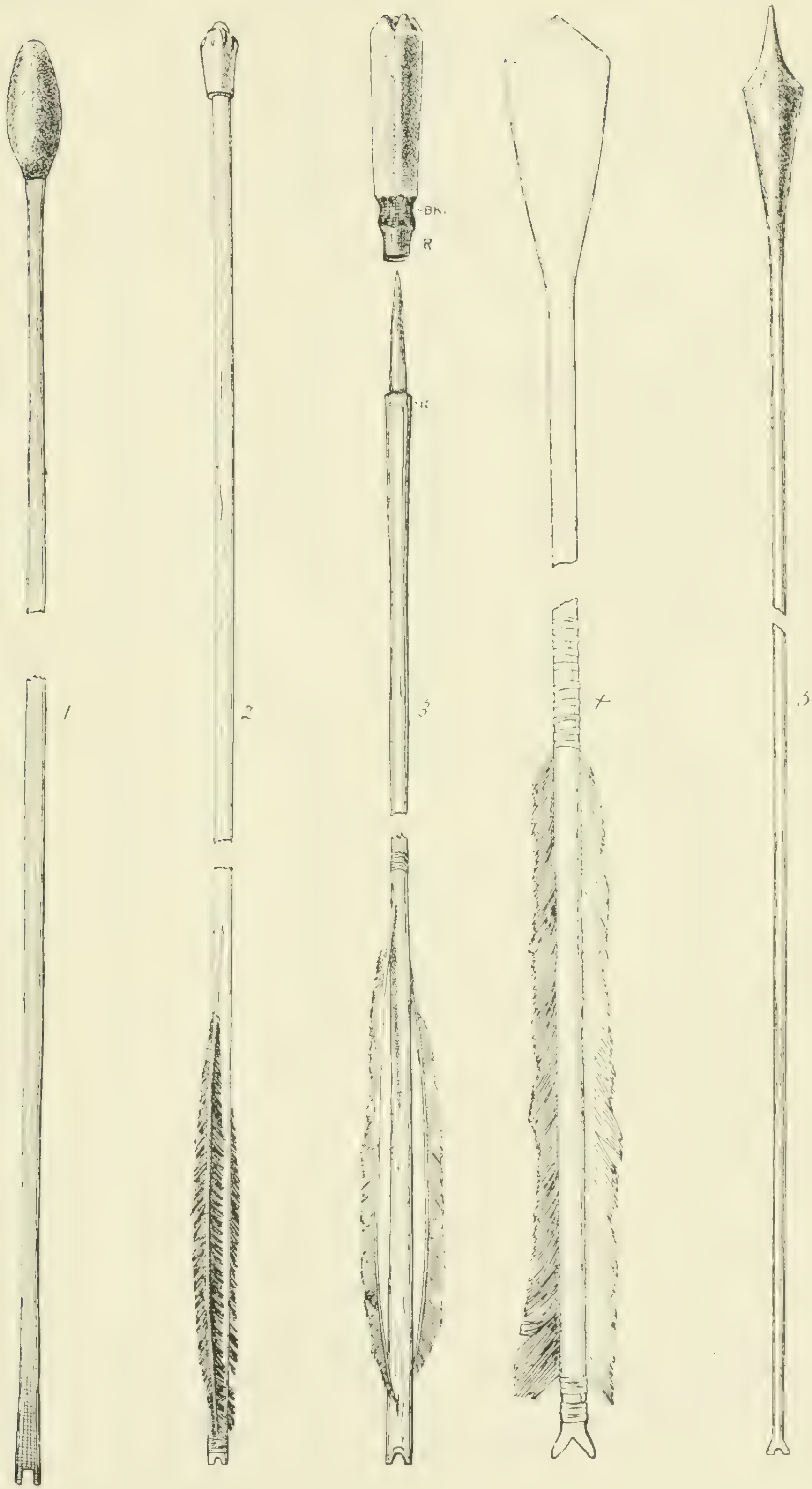
Fig. 4. Shaft, a piece of hard wood, cut down so as to leave the tip of the shaft and the nock wide spreading. Feathers, three, long, fastened to the shaft by wide strips of sinew. No ornamentation, but very carefully made. Length, 27 inches.

Cat. No. 23736, U. S. N. M. Indians of Devil's Lake. Collected by Paul Beckwith.

Fig. 5. The whole arrow is of a single piece, without feathers. The head is a double pyramid. The nock is much expanding; the notch, shallow. In the companion arrow to this one the head is a double cone. Total length of shaft, 24½ inches.

Cat. Nos. 8509 and 8508, U. S. N. M. Shoshones. Collected by Mr. Waters.

PLATE LIV.



BIRD BOLTS FROM VARIOUS AREAS.

EXPLANATION OF PLATE LV.

Western Eskimo Barbed Arrows.

Fig. 1. The shaft tapers both ways from the middle and is flattened at the nock. Feathers, two, laid on spirally and seized at the end with sinew. Nock, flat; notch, U-shaped. The blade of the head is sagittate, and there are two barbs on each side of the tang, which is inserted in the end of the shaft and seized with sinew. Length, 29 inches.

Cat. No. 72765, U. S. N. M.; also 72759. Ooglaamie Eskimo, Point Barrow. Collected by Capt. P. H. Ray, U. S. Army.

There is a great variety of form in this class of arrows, the design being always the same. In one specimen the tang is cylindrical and a series of barbs is filed on the edges of the blade. In another the tang is made of walrus ivory, and the iron blade inserted into the end of this tang has barbs on the lower edges of the blade. In another specimen one-half of a pair of scissors is used as a head. The part in front of the hinge, filed with two edges, forms the blade, and the part behind the hinge is filed and straightened out so as to form the tang and a very efficient barb. This is a remarkable specimen of the adaptive genius of this people. In the shaping and filing of this scissors blade all of the characteristics and marks of the barbed arrow with a stone head are preserved, except that the metal is substituted for the bone and stone.

Fig. 2. Shaft, of spruce wood, cylindrical. Shaftment, gradually flattened toward the nock. Feathers, two, extending off from the shaft, and seized with sinew-twisted thread. The nock is flattened; notch, parallel-sided. The barb, a piece of antler, sharpened at one end, inserted into the end of the shaft, and seized with fine sinew thread. The four barbs are on one side of the barb piece, and they project from the shaft, as in a feather, and this effect is emphasized by a little furrow just where the barbs proceed from the shaft. The point, a formidable blade of iron, with jagged barbs at the lower extremities, inserted into a "saw cut" on the end of the barb piece and fastened with a copper rivet.

Cat. No. A and B. 43352, U. S. N. M. Eskimo, Upper Yukon. Collected by E. W. Nelson.

Fig. 3. Shaft, of spruce, cylindrical, flattened towards the end. Feathers, two, seized with sinew twine. Nock, flat; notch, U-shaped. The head is in two parts. The shank is barbed on one side, inserted into the end of the shaft, and seized with twisted sinew. The head is sagittate; the tang inserted into a cut in the end of the shank and seized with sinew. Total length of shaft, 29½ inches.

Fig. 4. Similar to fig. 3, excepting that the head is all of iron. The long shank is serrated on the edges and the leaf-shaped blade has also barbs near the base. Length, 25¾ inches.

Cat. No. 875, U. S. N. M. Mackenzie River. Collected by R. W. MacFarlane.

Fig. 5. Shaft, of spruce, cylindrical. Shaftment, flat. Feathers, two, seized at the end with twisted sinew, standing off from the shaftment. The nock is flat and seized with twisted sinew; notch, U-shaped. The head is a piece of sheet iron inserted into a cut in the end of the shaft and seized with twisted sinew. Three abnormally large barbs on each side of the head. Length, 30 inches.

Cat. No. 1966, U. S. N. M. Mackenzie River. Collected by R. W. MacFarlane.

FIG. 6. SHAFT of spruce. The head is of steel or iron. On each side of the head are six sharp barbs put in with a file, and a portion of the long tang protruding from the shaft is also serrated. The head is split, the tang driven in and held in place by a lashing of sinew twine. Feathers, two, seized at the end by narrow bands of sinew cord and standing off from the shaft. This type of arrow is evidently the direct descendant of the aboriginal form, in which the head consists of a barbed piece and the blade. These murderous heads of iron exist in great variety over the Mackenzie region and have evidently been procured by the Eskimo from the Hudson Bay Company. A collection of them is a very interesting study in the variation of the arrowhead. Length of shaft, 2 feet; foreshaft, 5 inches.

Cat. No. 875, U. S. N. M. Mackenzie River Eskimo. Collected by R. Kennicott.

NOTE.—Specimens exist in the National Museum in which the iron blade is attached to the bone barbed piece thus, and also specimens in which the blade is of bone. Thus connection between the three types is established.

WESTERN ESKIMO BARBED ARROWS.

EXPLANATION OF PLATE LVI.

NORTHWESTERN ESKIMO RANKLING ARROWS.

FIG. 1. SHAFT, of spruce wood, cylindrical. Shaftment, flat. Feathers, two, seized with sinew. The nock is flat; the notch, U-shaped. The head is a triangular piece of ivory driven into the end of the shaft, and is seized with sinew. The point is formed by shaving off the sides of the pyramid. Total length, 25 inches.

Cat. No. 89904, U. S. N. M. Eskimo of Point Barrow, Alaska. Collected by Lieut. Ray, U. S. Army.

FIGS. 2, 3, 4. SHAFT, of spruce, the head is a piece of bone sharpened at the point, and on the sides are cut barbs, which vary in number among different examples. The head is set very loosely into a socket in the end of the shaft by means of a tapering dowel, the object being to leave the head to rankle in the deer or other animal killed. There is a great variety of these rankling arrows in the collection of the National Museum. Length of shaft, 2 feet 11 inches; foreshaft, 8 inches.

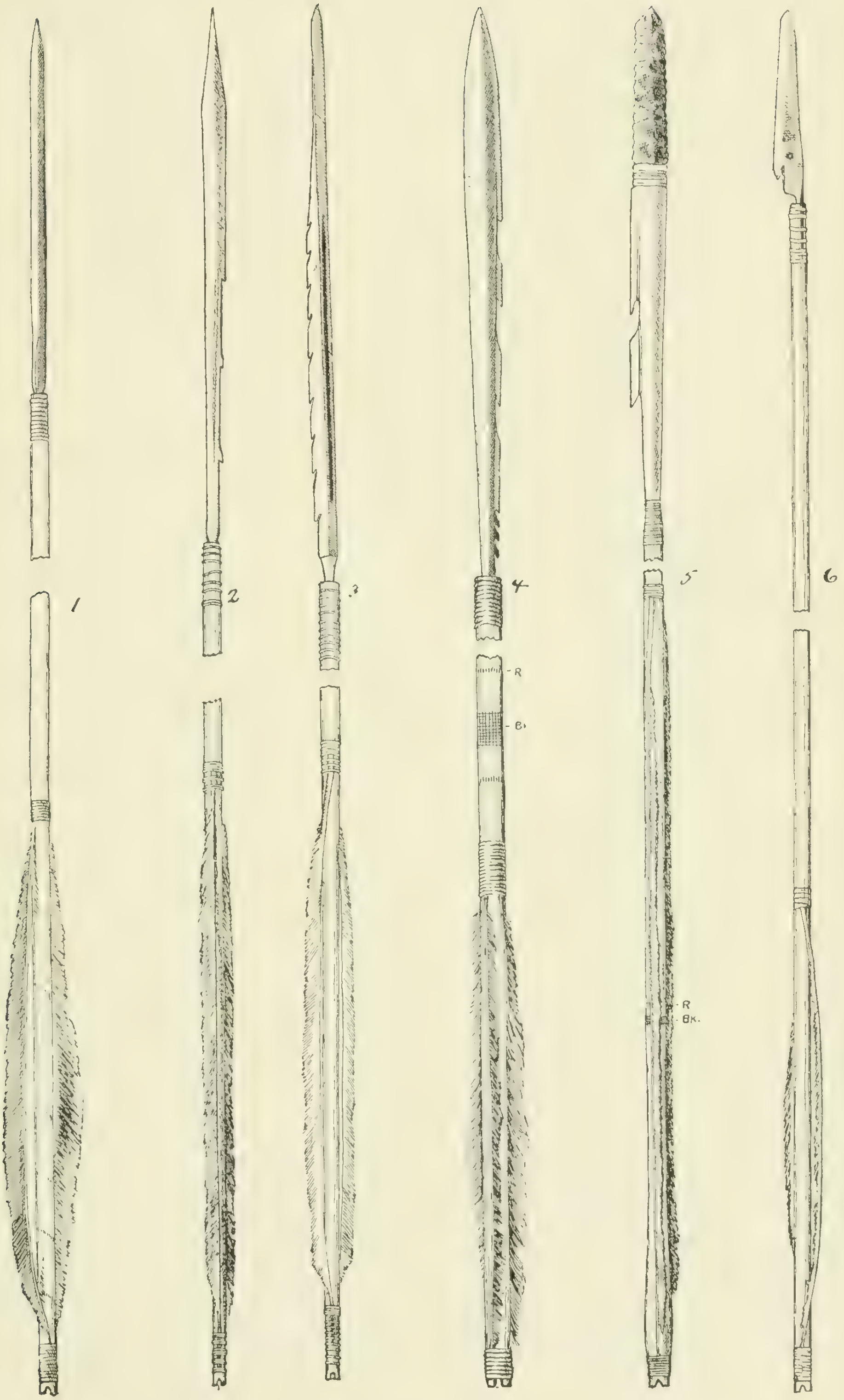
Cat. No. 2674, U. S. N. M. Eskimo of Fort Anderson River. Collected by G. R. McFarlane.

FIG. 5. SHAFT, cylindrical. Shaftment, flattened transversely to the plane of the arrowhead. Feathers, three, laid on flat and seized with twisted sinew. Notch, angular. The head of this arrow consists of two parts—the barb piece and the point. The barb piece is of bone or antler pointed and inserted into the end of the shaft and seized with sinew. Barbs, two, standing out from one side. The arrowhead, of chert, neatly chipped, hastate-shaped, inserted into a slit in the end of the barb piece and seized with sinew, which is laid on in a groove. These points are very easily drawn out. Other specimens from this same quiver vary in size of the barb piece and the length and serrations of the chipped blade. Total length of shaft, 30 inches.

Cat. No. 72785, U. S. N. M. Eskimo of Point Barrow. Collected by Capt. Ray, U. S. Army.

FIG. 6. SHAFT, of spruce. Feathers, two, loosely laid on and fastened with sinew. Head, one blade of a pair of scissors driven into the shaft and seized with rawhide. Length of shaft, 25 inches; foreshaft, 5 inches.

Cat. No. 72757, U. S. N. M. Eskimo of Point Barrow. Collected by P. H. Ray, U. S. Army.



NORTHWESTERN ESKIMO RANKLING ARROWS.

EXPLANATION OF PLATE LVII.

BIRD BOLTS OF NORTHWESTERN ESKIMO.

FIG. 1. SHAFT, of wood, and the head, of bone, or ivory, or antler, is set on like the head of a cane and rounded. In one of the examples the end of the shaft is split and the head is held in by a wedge-shaped dowel. Bird arrow. Length, about 21 inches.

Cat. Nos. 24579–80, U. S. N. M. Eskimo, St. Michaels, Alaska. Collected by Lucien Turner.

NOTE.—There is a great variety of these bird arrows used for the purpose of stunning water fowl. The shaft is a simple rod of different material, and the head is held on in various ways and seized with sinew.

FIG. 2. SHAFT, cylindrical. Shaftment, flattened. Feathers, three, held on with twisted sinew. Nock, flat; notch, U-shaped. The head is in the conventional form of the Eskimo bird arrowheads, fitted on to the wedge-shaped end of the shaft and seized with sinew. Length, 27 inches.

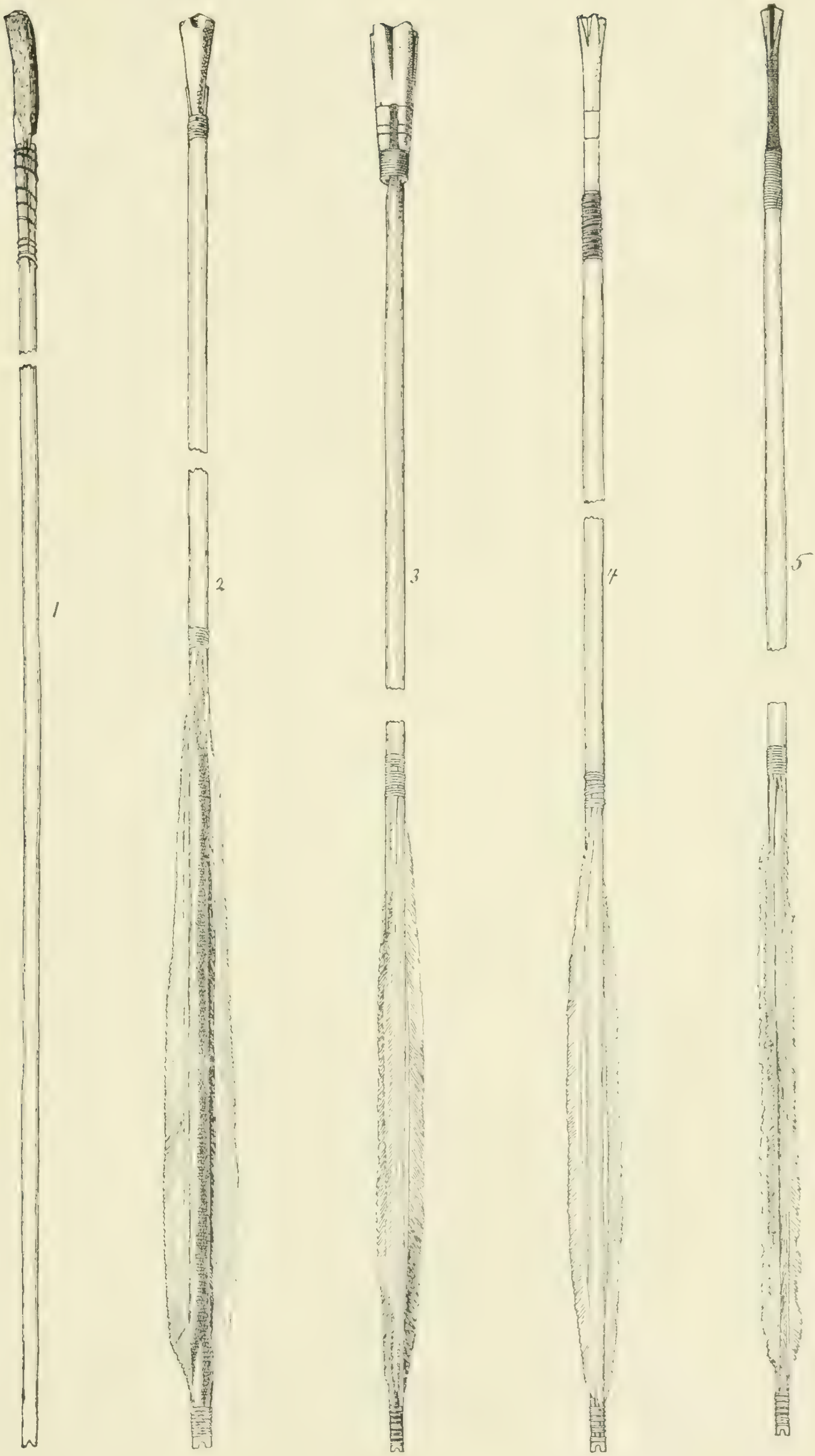
Cat. No. 72772, U. S. N. M. Point Barrow. Collected by Capt. P. H. Ray, U. S. Army.

FIGS. 3, 5. SHAFT, of spruce, cylindrical. Shaftment, flattened at the end. Feathers, three, seized with twisted sinew. Nock, flat; notch, angular. Head, of iron, in imitation of the standard Eskimo bird arrow, the head of which is a club-shaped piece of ivory or bone with notches cut in the end so as to give the shape of a cross in section. This is designed to wound the bird and bring him down without shedding his blood.

FIG. 4. Precisely similar to fig. 3, excepting that the head is of ivory, and there are only two feathers. Length of both arrows, 27 inches.

Cat. No. 1106, U. S. N. M. Eskimo, Mackenzie River. Collected by R. MacFarlane.

NOTE.—In some samples under this number the ivory or bone heads are ornamented with lines cut in. The shaft of the arrow is cut wedge-shaped, inserted into the long notch at the base of the head, and nicely seized with sinew, which is laid on in a groove or countersink cut into the base of the bone head. The workmanship of this arrow is excellent.



BIRD BOLTS OF NORTHWESTERN ESKIMO.

EXPLANATION OF PLATE LVIII.

COMPOUND ESKIMO ARROWS, WITH TWO FEATHERS, OR NONE, AND FLAT NOCKS.

FIG. 1. SHAFT, cylindrical. No feathers. Nock, flat; notch, large and U-shaped. The head consists of a long shank of bone, in the end of which an iron blade is inserted and held in place by an iron rivet. The arrow shaft is cut wedge-shaped and fitted into an angular notch in the bone shank, held in place by wooden rivets, and seized with sinew. Total length, 26½ inches.

FIG. 3 is similar to fig. 1.

Cat. No 2529, U. S. N. M. Asiatic Eskimo. Collected by Commodore Rodgers, U. S. Navy.

FIG. 2. SHAFT, short and rudely made. Head is in two parts; the long shank of iron, on the outer end of which a blade of iron is riveted. Feathers, two, laid on flat and held in place by sinew. All of the specimens from this region are very poor, owing to the lack of wood, and they are also much modified by contact with the whites (thanks to the early appearance in this region of whale ships). Compare fig. 4. Length, shaft, 2 feet 2 inches; foreshaft, 6 inches.

Cat. No. 30016, U. S. N. M. Eskimo of Cumberland Gulf. Collected by W. A. Münster, U. S. Navy.

FIG. 4. THE SHAFT is of pine. The head consists of two parts, a shank of bone and a blade of iron let into the saw cut and riveted in place. The shank is spliced onto the shaft and seized with sinew twine. Feathers, two, laid on flat and held in place by a rough wrapping of sinew. Nock, flat. In this same number are other specimens differing from the one described in minute particulars. One specimen has a common nail for the head, with a piece of nail let in transversely as a stop. Other examples are unfinished. Length of shaft, 2 feet 1 inch.

Cat. No. 90138, U. S. N. M. Whale River Indians, Eskimo stock, Labrador. Collected by Lucien Turner.

FIG. 5. The type is fully described and figured in Pl. LIX.

COMPOUND ESKIMO ARROWS, WITH TWO FEATHERS OR NONE AND FLAT NOCKS.

EXPLANATION OF PLATE LIX.

THE DISSECTION OF A SEA-OTTER ARROW, COOK'S INLET.

This is the most elaborate and ingenious arrow known, and all of its parts, in every specimen, are most delicately finished. Such a weapon may well have been used in hunting the most costly of fur-bearing animals—the otter.

The shaft is of spruce, gently tapering toward the nock, which is large and bell shape. Into the end of this shaft is inserted a foreshaft of bone, and into the end of this fits the barb. Feathers, three, symmetrically trimmed and seized at both ends with delicately-twisted sinew thread. The barbed head is perforated, and through these perforations is attached a braided line at least ten feet long. The other end of the line is attached to two points on the shaft by a martingale. When not in use, the line is coiled neatly on the shaft and the barb is put in place in the foreshaft. When the arrow is shot, the barb enters the flesh of the otter, the loose fastening is undone, the line unrolled, the foreshaft drops into the arrow; the shaft acts as a drag and the feathers as a buoy to aid the hunter in tracing the animal. See fig. 4., Pl. LII.

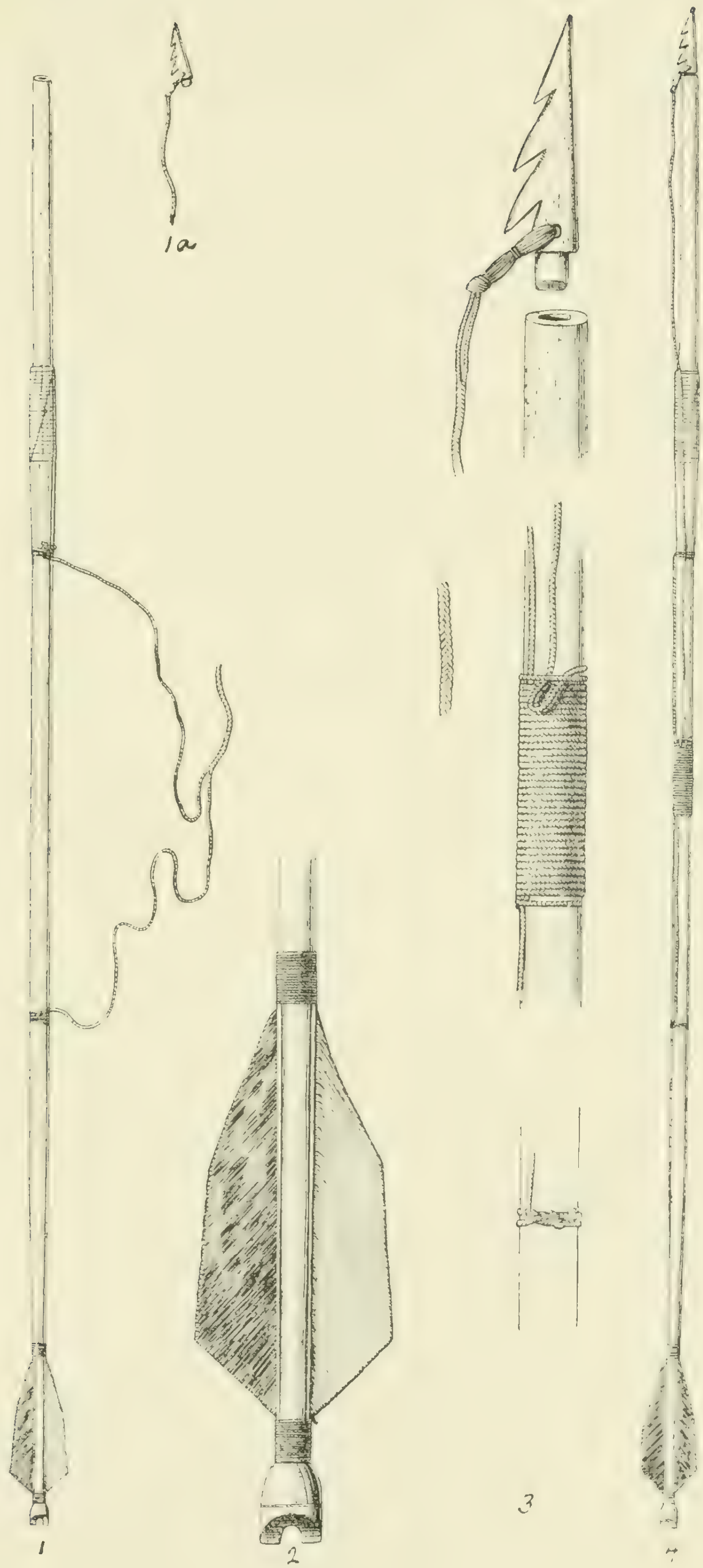
FIG. 1. Arrow with line unrolled showing relation of parts.

FIG. 2. The shaftment. Attention is drawn to the delicate seizing with sinew thread, the natty trimming of the feather, the most efficient nock.

FIG. 3. The lines and knots. Notice is given of the elegance of the braid, the efficient manner of "doing up" the line, the peculiar knot for the martingale.

FIG. 4. The arrow ready to be shot.

This form of arrow with its southern type of sinew-backed bow is found also on the Keniles, where these were taken by Aleuts, carried over by the Russians to hunt sea otter.



THE DISSECTION OF A SEA OTTER ARROW, COOK'S INLET.

EXPLANATION OF PLATE LX.

ARROWS WITH STOPS, RETRIEVING BARBS, OR COMPOUND PILE.

FIG. 1. Made of pine wood; the shaft, head, and point cut out of one piece. Feathers, three, 4½ inches long, laid on flat in the following manner: The three feathers were first attached to the butt of the arrow by a coiled wrapping of sinew, their other extremities pointed backward; then they were doubled backward and the ends seized with sinew. This makes a very secure fastening for the feather. The coiled wrapping is continued over the nock and fastened off in the notch. Nock, flat; notch, U-shaped. The head, bulbous. The point is cut out of this by whittling away the wood so as to leave a long projection like a nail or spike. Total length, 31½ inches.

Cat. No. 90123, U. S. N. M. Eskimo, Ungava. Collected by L. M. Turner.

FIG. 2. Very rudely made. Shaft, of spruce. Shaftment, flat. Feathers, two, laid on flat, seized with sinew. The nock is flat and the notch angular. Head, a common cut nail, driven into the end of the shaft and seized with sinew. At the inner part of this seizing a piece of nail is lashed on crosswise so as to prevent the arrow going more than two inches into the body of the the game. Total length of shaft, 25 inches.

Cat. No. 90138, U. S. N. M. Whale River, Hudson Bay. Collected by Lucien Turner.

FIG. 3. THE SHAFT, of osier. There is no feather. The nock is tightly seized with sinew cord; notch, U-shaped. The peculiarity of this arrow is that the point, of iron or bone, is lashed to the beveled end of the shaft and the tang is projected backwards into a long barb. This arrow is used in shooting prairie dogs. It is said that the Navahoe uses now a little bit of mirror with which to throw the sunlight into the eyes of the prairie dog until he can get near enough to drive one of these arrows into his body. Upon the least alarm or injury the creatures dive into their holes and this arrow enables the hunter, if he strikes one of them, to retrieve his game. The action of this arrow is very similar to that of the vermin hook used by the Ute Indians, and also to those of the northwest coast. Total length of shaft, 33 inches (32½ inches).

Cat. No. 126740, U. S. N. M. Navahoe Indians. Collected by Thomas Keam.

FIG. 4. THE SHAFT is of spruce wood, ornamented here and there with band of red paint, cylindrical. Shaftment, flat. Feathers, three, seized at their ends with twisted sinew thread. One feather is in the middle of one of the flat sides; the other two feathers are at the round corners of the other side. The flat nock flares a little upward, and the notch is angular. This is a bident or double-pointed arrow, having two barbs of bone inserted into the end of the shaft, so as to give them a spread of three-fourths of an inch at their points, one of which is a little longer than the other. They are held to the shaft by a wrapping of sinew cord. The barbs face inward. Total length of shaft, 26 inches.

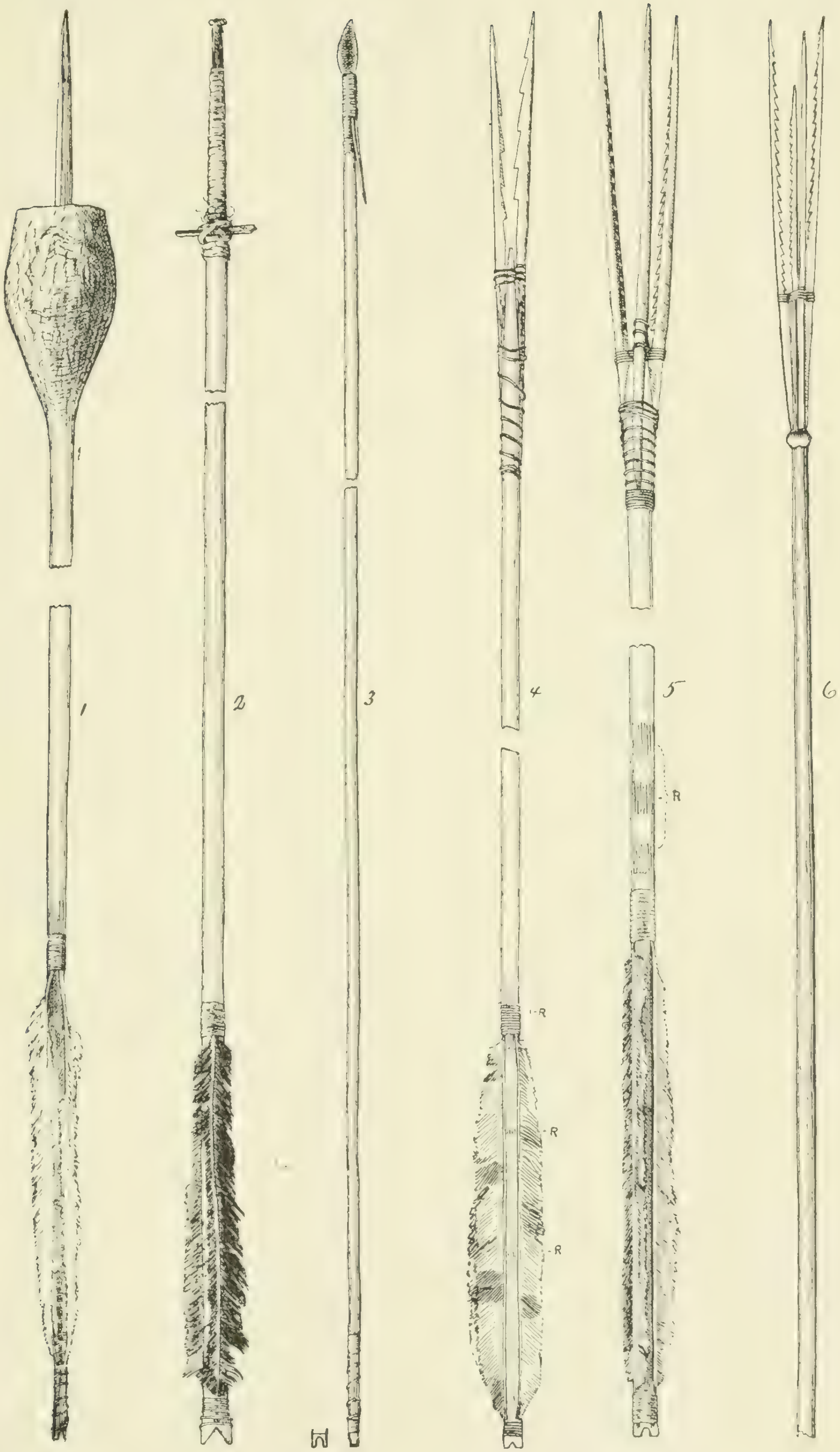
Cat. No. 76705, U. S. N. M. Eskimo, Bristol Bay; Fort Alexandra, Alaska. Collected by J. W. Johnson.

FIG. 5. SHAFT, of spruce, painted red. Feathers, three, roughly seized with sinew. Nock, flat; notch, U-shaped. The three barbs of the trident are inserted in the end of the shaft so as to be about an inch apart at the outer point. The barbs, of bone, are serrated on the inside. They are held in place by a wrapping of sinew cord at their lower extremities, a curious braid of the same cord attaching them to the tip of the shaft and holding them in place. Length of shaft, 35 inches.

Cat. No. 72413, U. S. N. M. Southern Alaska. Collected by Charles McKay.

FIG. 6. SHAFT, of spruce wood. The lower end has been broken off. The upper portion of this weapon deserves especial study. A little band of ivory, fitted over the shaft, 1½ inches from the upper end. Precisely similar bands are frequently labeled ornaments. Into the extremity of the shaft is inserted a delicate point of walrus ivory, triangular in cross section. Two of the edges are finely barbed. Three larger barbs, also triangular in section, have their lower ends driven into the shaft under the ivory band, and the edges lie along in grooves extending to the end of the shaft. The barbs of these three points are on the inside. Just at the end of the shaft each of these outer barbs is perforated, and sinew thread attaches them together and also to the central barb, and is also wrapped around the bases of these barbs just above the ivory band. Length of outer barbs, 6 inches.

This arrow represents a type Cat. No. 48342, U. S. N. M. Nunivak Island. Collected by E. W. Nelson.



ARROWS WITH STOPS, RETRIEVING BARBS, OR COMPOUND PILE.

EXPLANATION OF PLATE LXI.

PLAIN BOWS FROM THE SOUTHWEST, AND SINEW-LINED, NARROW TYPE.

FIG. 1. Bow, of hard wood, rudely whittled out of a pole, showing bark and knots on the back. Length, 4 feet 6 inches. Notice that bows equally rude are found at Tierra del Fuego.

Cat. No. 1976, U. S. N. M. Dieguenos Indians, San Diego, California. Collected by Dr. Edward Palmer.

FIG. 2. Bow, of mesquit wood. Rectangular in cross section, tapering from the grip; single curve. Bow string of two-ply sinew cord. Length, 3 feet 6 inches.

Cat. No. 126643, U. S. N. M. Tarahumara, Chihuahua, Mexico. Collected by Dr. Edward Palmer.

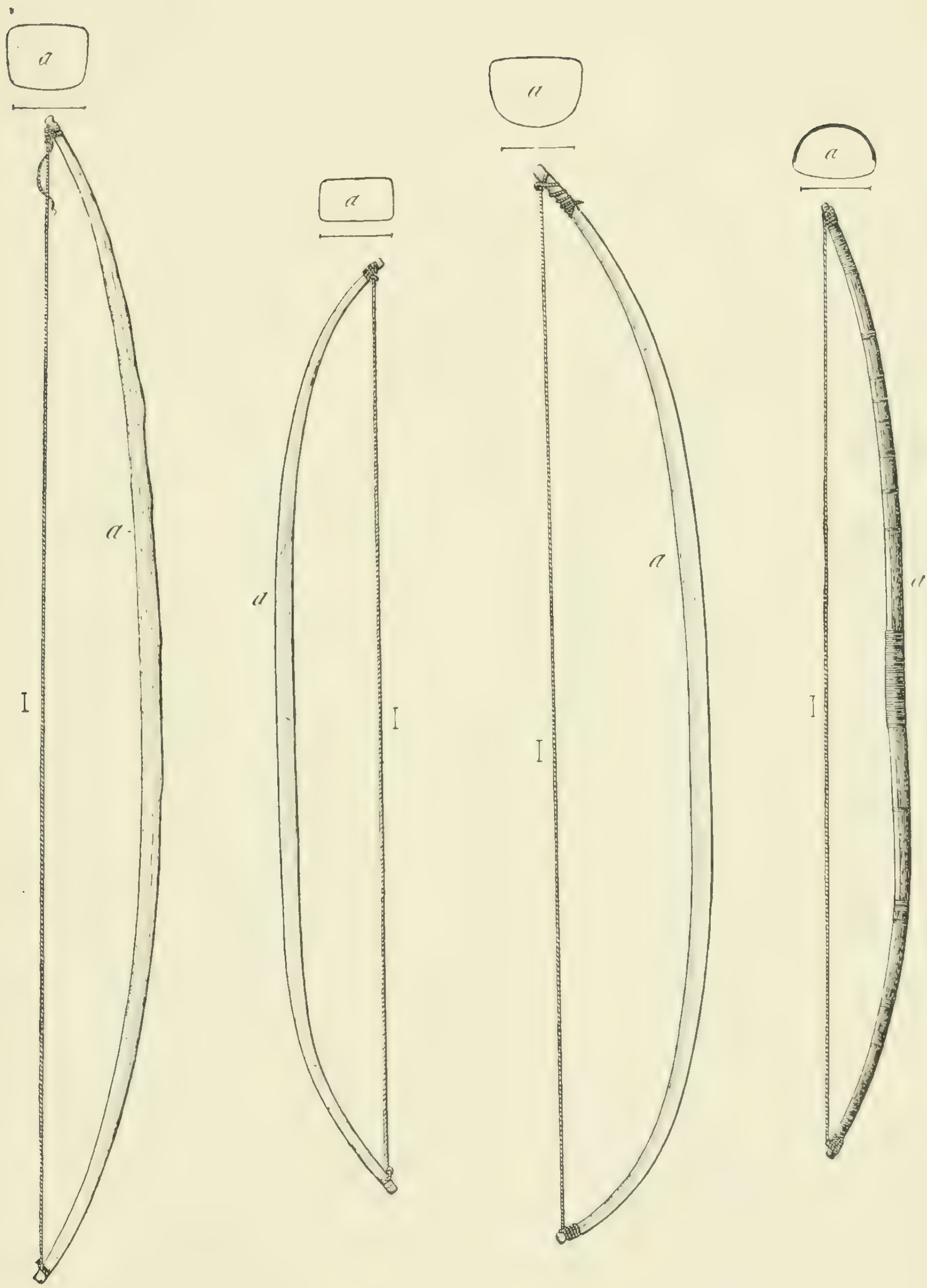
FIG. 3. Bow, of cotton wood, cut out of a rod leaving the back untrimmed; single curve. Bow string of sinew cord, two-ply. Length, 4 feet 6 inches.

Cat. No. 76021, U. S. N. M. Pima Indians, Arizona. Collected by Dr. Palmer.

It should be remarked that these plain bows with rounded and rectangular cross section represent the whole area southward to Cape Horn.

FIG. 4. SINEW-LINED BOW made of hard wood. Back lined with sinew and laid on with glue; reenforced by fifteen transverse bands of sinew. The grip wrapped with buckskin string. The bow string of sinew cord, two-ply. Length, 3 feet 8 inches.

Cat. No. 75156, U. S. N. M. Navajo Indians, New Mexico. Collected by Bureau of Ethnology.



PLAIN BOWS FROM THE SOUTHWEST, AND SINEW-LINED BOW, NARROW TYPE.

EXPLANATION OF PLATE LXII.

PLAIN, SINEW-LINED, AND COMPOUND BOWS, THE LAST NAMED ALSO SINEW-LINED.

FIG. 1. Bow of hard wood, ovoid in section, single curve; string of sinew cord. Length, 4 feet 1 inch.

Cat. No. 130616, U. S. N. M. Crow Indians, Montana. Collected by Maj. C. S. Bendire, U. S. Army.

FIG. 2. Bow, made of hickory, with a double curve—the lower curve larger than the other. The back neatly lined with sinew, and the ends wrapped for two or three inches with shredded sinew. Grip bound with buckskin string. Bowstring, three-ply sinew cord, back painted white. Length, 3 feet 5 inches.

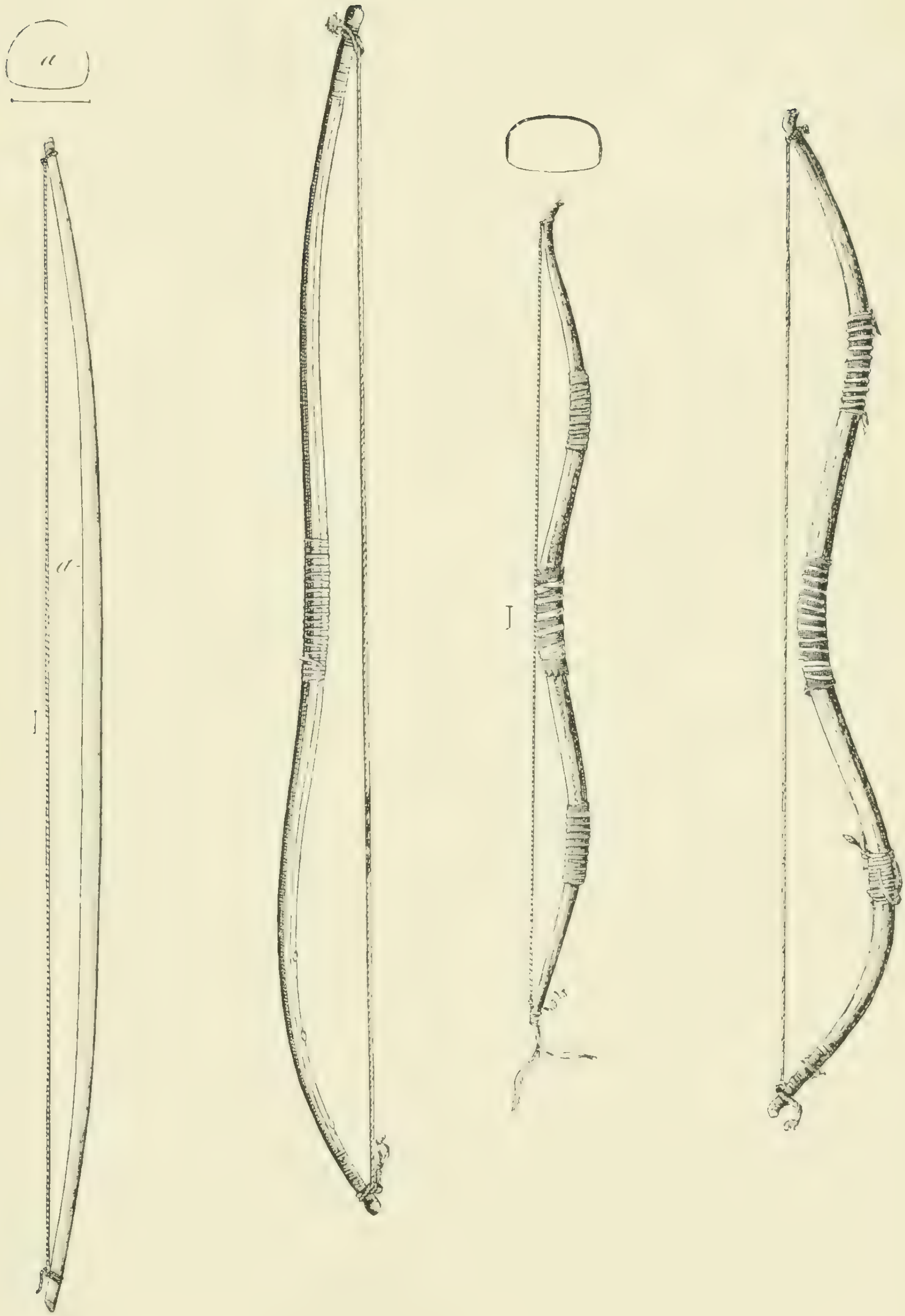
Cat. No. 8418, U. S. N. M. Gros Ventres, Dakota. Collected by Dr. Washington Mathews, U. S. Amry.

FIG. 3. COMPOUND BOW, made of two sections of cow's horn, spliced together in the middle and held by three rivets. Lined on the back with sinew, which covers also the nocks. Curved in shape of Cupid's bow, bound at the grip and the curve of the limbs with bands of red flannel, which is held in place by seizings of buckskin string wrapped here and there with broad quill, dyed yellow. The horns are also wrapped with shredded sinew. Bowstring, a three-ply sinew cord End of the bow ornamented with tufts of horsehair and fur. Length, 3 feet.

Cat. No. 154015, U. S. N. M. Sioux Indians, Montana. Collected by Gen. Hazen, U. S. Army.

Special attention is called to the union of the compound and sinew lined bow in one specimen.

FIG. 4. Similar to No. 3, but was collected long ago from the Gros Ventres, Upper Missouri, by Dr. Washington Mathews, who spent a number of years among these people. Contact with the Great Interior Basin is shown by the union of the compound bow and the Shoshonean type of sinew-lined bow. Length, 36 inches.



PLAIN, SINEW-LINED, AND COMPOUND BOWS, THE LAST NAMED ALSO SINEW-LINED.

EXPLANATION OF PLATE LXIII.

SINEW-LINED BOWS, BROAD TYPE. ONE BOW PLAIN.

FIG. 1. BOW, made of yew. This is a bow with a single curve on the back, double curve on the inside, broad and flat. Constricted at the grip and narrowing toward the nocks. Along the inside is a little furrow. The grip is ornamented with a tuft of long hair seized in place by a band of birch bark. This bow is exactly of the form of the sinew-lined bows farther south and inland. Perhaps the cold and dampness of the coast regions are unfavorable, affecting the glue. The bowstring is a single ribbon of sinew twist. Length, 3 feet 10 inches.

Cat. No. 72656, U. S. N. M. Makah Indians, Cape Flattery. Collected by J. G. Swan.

FIG. 2. BOW, made of yew and lined along the back with sinew, shredded and mixed with glue, which is wrapped around the horns of the bow and molded to form the nocks. Single curve, excepting at the ends where the limbs turn gracefully backward. The grip and horns are wrapped with buckskin string. Bowstring, sinew cord, three-ply. Length, 3 feet 5 inches.

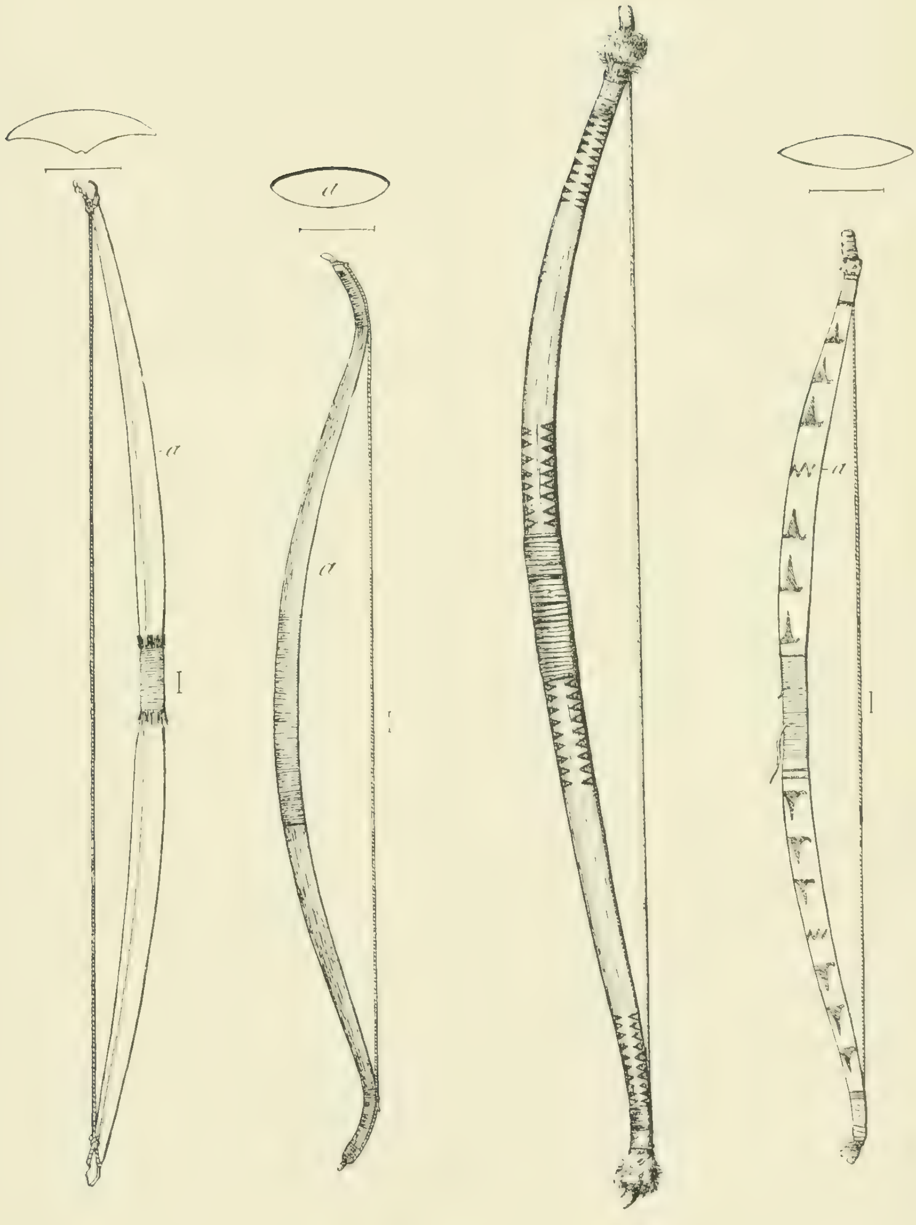
Cat. No. 2058, U. S. N. M. Tejon Indians, California. Collected by John Xantbus.

FIG. 3. BOW, made of yew wood. Broad and thin at the grip, tapering in width and thickness toward the nocks, which are turned outward. The back of the bow is lined with shredded sinew, laid on closely like the bark on a tree, and painted green and decorated with tufts of otter skin and strips of dressed hide, seized with sinew. The grip is covered with a seizing of buckskin string. The horns of the bow turn outward. The bowstring is made of twisted sinew. Length, 3 feet 10 inches.

Cat. No. 19322, U. S. N. M. McCloud River Indians, Copehan stock, California. Collected by Livingston Stone.

FIG. 4. SINEW-LINED BOW, made of yew. Broad and flat, lined on the back with sinew laid on in glue and ornamented with figures painted green. Narrowed somewhat at the grip and bound with buckskin string. Around the horns buckskin is glued and bands of sinew wrapped and the nocks ornamented with tufts of fur. Bowstring is a loose twine of sinew cord. Length, 3 feet 8 inches.

Cat. No. 131110, U. S. N. M. Pitt River Indians, Northern California. Collected by N. J. Purcell.



SINEW-LINED BOWS, BROAD TYPE. ONE BOW PLAIN.

EXPLANATION OF PLATE LXIV.

PLAIN BOWS. ONE EXAMPLE COMPOUND WITH SINEW CABLE BACKING.

FIG. 1. BOW, of hickory. Rectangular in cross-section. Double curve, tapering toward the ends. Bowstring of very thick three-ply sinew cord. Length, 4 feet.

Cat. No. 129873, U. S. N. M. Arapaho Indians, Nebraska. Collected by H. M. Creel.

FIG. 2. BOW, of willow; oval in section, tapering toward the ends slightly, double curve. Chief characteristic is a piece of wood on the inside of the grip, fastened like the bridge of a violin, and held in place by a buckskin cord to catch the blow of the string in relaxing. The bowstring is a tough one of rawhide. Length, 4 feet 5 inches.

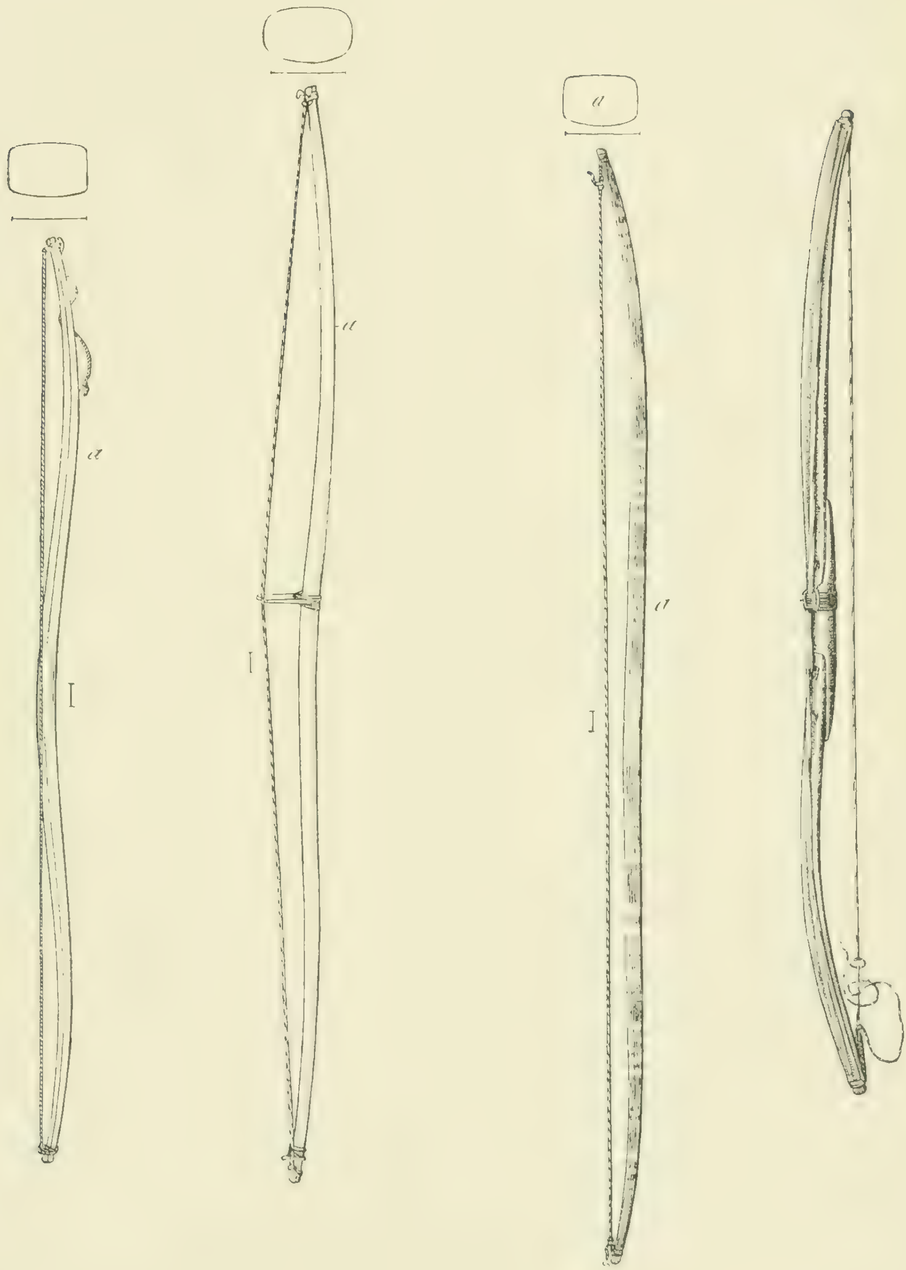
Cat. No. 75455, U. S. N. M. Kutchin, Inland Alaska. Collected by J. J. McLean.

FIG. 3. BOW, of willow; similar to 75455. Evidently unfinished. It is a weak weapon, and the bowstring is made of cotton thread. Length, 4 feet 1 inch.

Cat. No. 63552, U. S. N. M. Kutchin Indians, Inland Alaska. Collected by J. J. McLean.

FIG. 4. COMPOUND BOW, made of three pieces of bone. The foundation is the grip or middle piece, to which the limbs are spliced and riveted. The back of this bow is slightly reenforced by five double strands of braided sinew or sennit, passing along the back from nock to nock, and held in place by a cross wrapping at the middle of the grip. Bowstring is made of four strands of sennit. The ends of this string are attached to loops of rawhide, which pass over the nocks. Length, 2 feet 8 inches.

Cat. No. 34055, U. S. N. M. Eskimo, Cumberland Gulf. Collected by Ludwig Kumlien.



PLAIN BOWS. ONE EXAMPLE COMPOUND WITH SINEW CABLE BACKING.

EXPLANATION OF PLATE LXV.

SINEW-BACKED BOWS OF ESKIMO.

FIG. 1. Compound bow, made of reindeer antler and backed with sinew. The specimen is from Cumberland Gulf, the farthest point east at which sinew-backed bows have been found. This is an interesting specimen also because it exhibits the method of making the compound bow after the advent of the whalers. The grip piece is spliced and riveted to the limbs. In the old régime these three pieces were fastened together by lashings of sinew cord or braid, very strongly at the points where the upper and lower seizing occur in this bow. Two views given. Murdoch says of this type: "The main part of the reenforcement or backing consists of a continuous piece of stout twine made of sinew, generally a 3-strand braid, but sometimes a twisted cord, and often very long (sometimes 40 or 50 yards in length). One end of this is spliced or knotted into an eye, which is slipped round one 'nock' of the bow, usually the upper one. The strands then pass up and down the back and round the nocks. A comparatively short bow, having along its back some dozen or twenty such plain strands, and finished off by knotting the end about the 'handle,' appears to have been the original pattern. The bow from Cumberland Gulf (fig. 1) is such a one, in which the strands have been given two or three turns of twine from the middle. They are kept from untwisting by a 'stop' round the handle, which passes between and around the strands."

Cat. No. 34053, U. S. N. M. Collected by L. Kumlien.

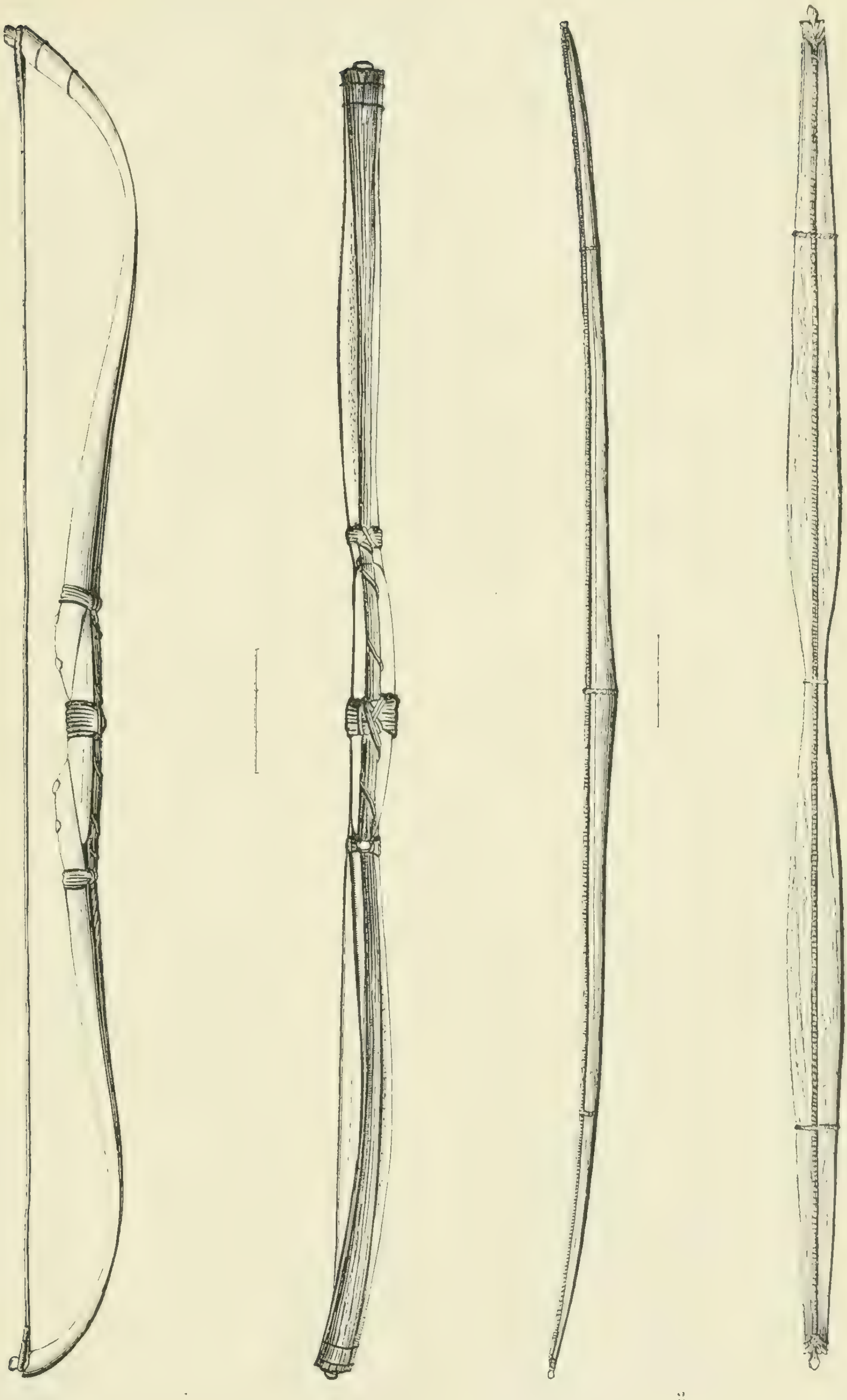
FIG. 2. Southern type of sinew-backed bows of Murdoch. The essential features of these southern bows are—

First. The substitution of a columnar for a breaking strain upon the wood secured by winding a great many yards of sinew twine or braid backward and forward along the back of the bow, from nock to nock.

Second. The addition of strands in the cable inserted by means of half-hitches at various points, laid on as shown in the following plate.

Third. Holding the strands together in a cable by a coiled twine running from end to end.

Cat. No. 36032, U. S. N. M., Cape Romanzoff, collected by E. W. Nelson. Straight bow with the simplest form of southern backing.



COMPOUND AND SINEW-BACKED BOWS OF ESKIMO.
(After Murdoch.)

EXPLANATION OF PLATE LXVI.

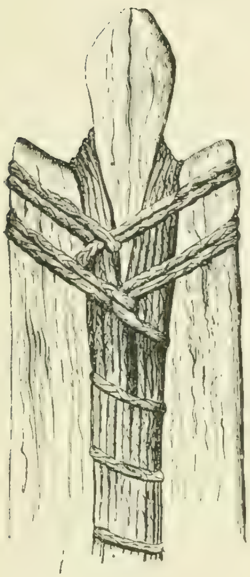
SINEW-BACKED BOWS OF ESKIMO. SOUTHERN TYPE.

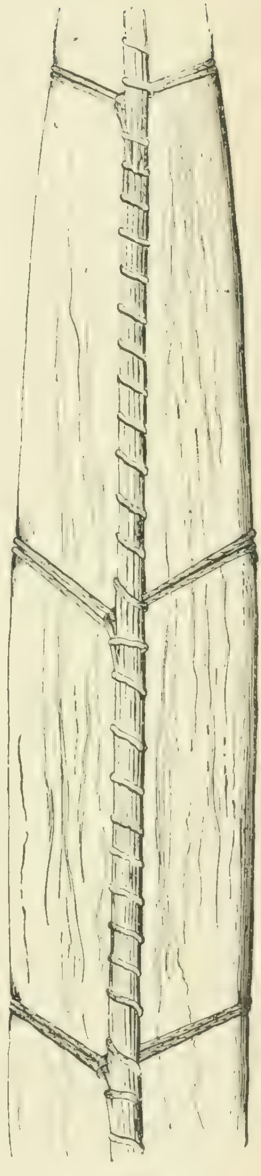
FIG. 2*a*. One end of fig. 2 in the last plate, showing the form of the nock, the character of the braid of sinew, the method in which the cable is built up, the half hitches made about the bow, and the coil laid about the cable.

Cat. No. 36032, U. S. N. M. Eskimo of Cape Romanzoff. Collected by E. W. Nelson. (After Murdoch.)

FIG. 3. Straight bow, with Murdoch's southern type of backing. The peculiarity of this bow is shown in fig. 3*a*. After nearly all the filaments in the cable have been passed from nock to nock, the bowyer, stopped with his braid at a certain point, made two half hitches, and then added a strand to the cable by going to an equidistant point on the other side of the grip. This was repeated three times on this bow and the braid fastened off in the middle. The mark at the side of the bow denotes inches.

Cat. No. 72408, U. S. N. M. Bristol Bay. Collected by C. L. McKay.





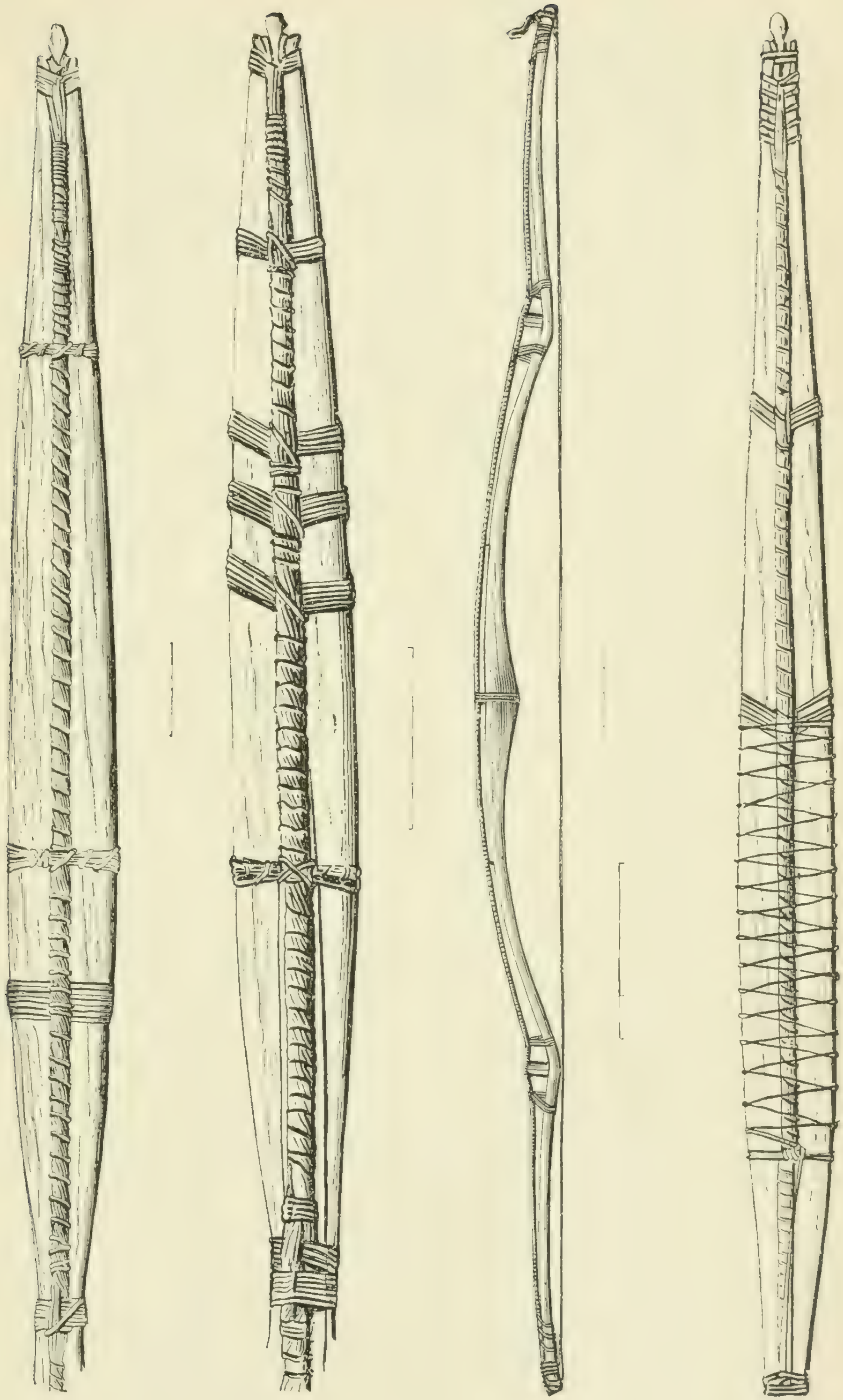
SINEW-BACKED BOWS OF ESKIMO, SOUTHERN TYPE.
(After Murdoch.)

EXPLANATION OF PLATE LXVII.

SINEW-BACKED BOWS OF ESKIMO.

PLATE LXVII represents four examples of sinew-backed bows of Murdoch's southern types. The following characteristics are to be noted: First, in all of them the backing extends from nock to nock with here and there extra strands let into the cable by means of any number of half hitches passing around the bow and into the cable. These have the additional value of keeping the wood from cracking. In the third example in the plate is exhibited the characteristics of the bent or Tatar pattern. The bow has really three curves, the great one in the middle and two shorter ones near the end. The bends where the small curves meet the larger one are strengthened with bridges of wood and seizing of sinew. In three specimens on the page the cable or backing has been twisted by means of an ivory lever described in the text and held thus by a seizing which is rove through one-half of the strands holding the whole in place. The twisting of the sinew serves to tighten the bow. In figures 4, 5, 7 the bow is shown with a device for keeping the cable from untwisting. In all examples except figure 6 one-half of the bow is shown.

In the order in which they appear upon the plate the bows are numbered Cat. No. 7972, U. S. N. M., from Bristol Bay, collected by Dr. Minor; No. 15651, Nuniviak Island, collected by W. H. Dall; No. 36028, Kuskoquim, collected by E. W. Nelson; No. 36034, collected by E. W. Nelson.



4 5 6 7

SINEW-BACKED BOWS OF ESKIMO, SOUTHERN TYPES.

(After Murdoch.)

EXPLANATION OF PLATE LXVIII.

SINEW-BACKED BOWS OF ESKIMO.

Plate showing Murdoch's Arctic type of bow. The noteworthy features are—

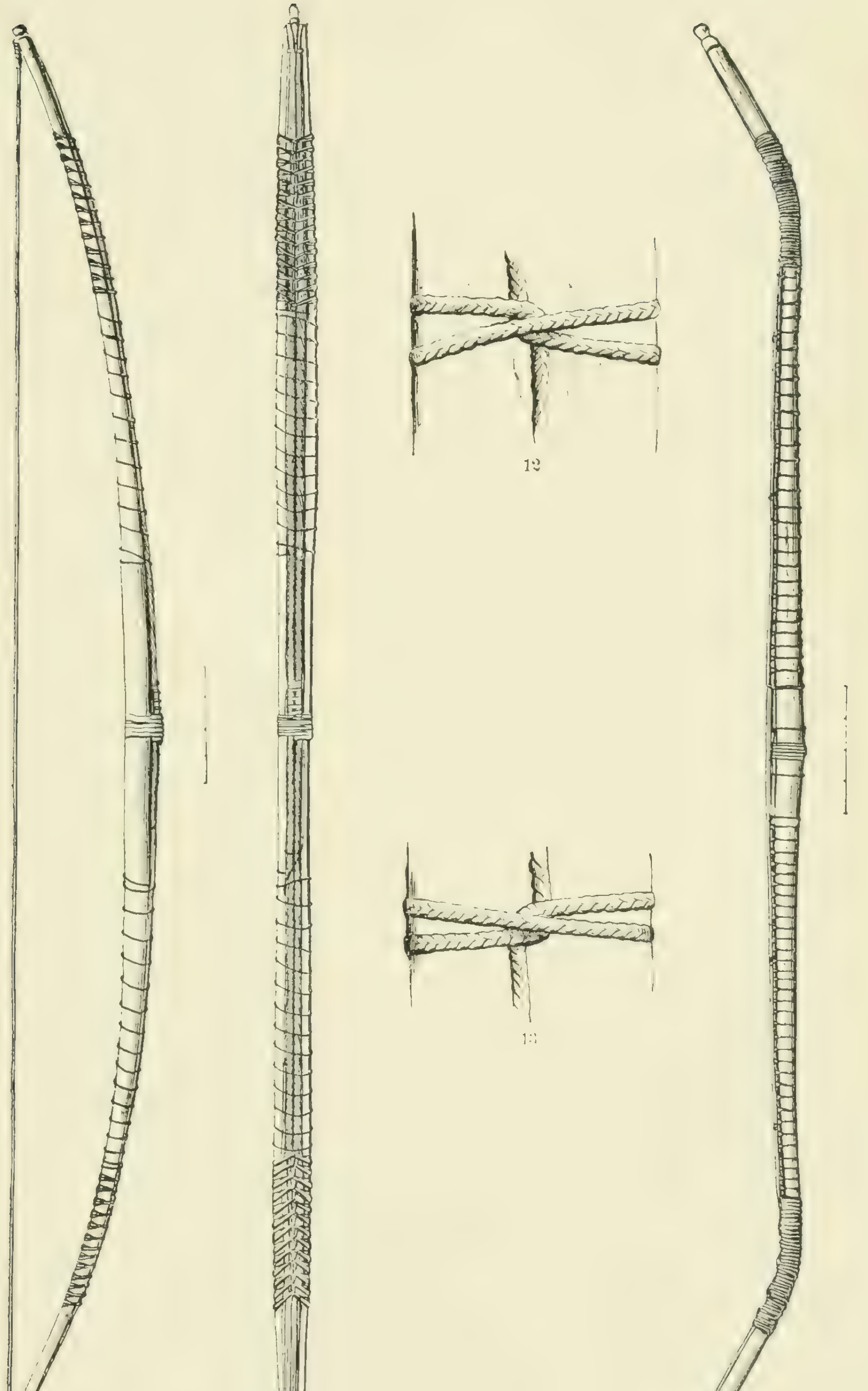
First. These bows are much shorter than those of southern type and are said by Murdoch to be of very graceful shape. In some examples the ends are bound up as in some of the southern bows and the back reenforced with a short rounded splint of wood or antler in the bend.

Second. The backing of these bows is always "of a very complicated and perfect pattern, usually very thoroughly incorporated with the bow by means of hitches and a very complete seizing of many turns running nearly the whole length of the bow and serving to equalize the distribution of the strain and thus prevent cracking."

Third. Another notable feature is in some examples the division of the backing into two cables in which the twist runs in opposite directions so that when the two cables are sewed together neither one can untwist. The examples shown in the plate are numbered as follows:

First. Cat. No. 1972, U. S. N. M. Arctic bow from the Mackenzie region, back and side view. Collected by Ross.

Second. Cat. No. 89245, U. S. N. M., from Point Barrow, collected by the U. S. International Polar Expedition. The wood is in shape of a Tatar bow. Figures 12 and 13 show the left-handed and right-handed "soldier's hitch."



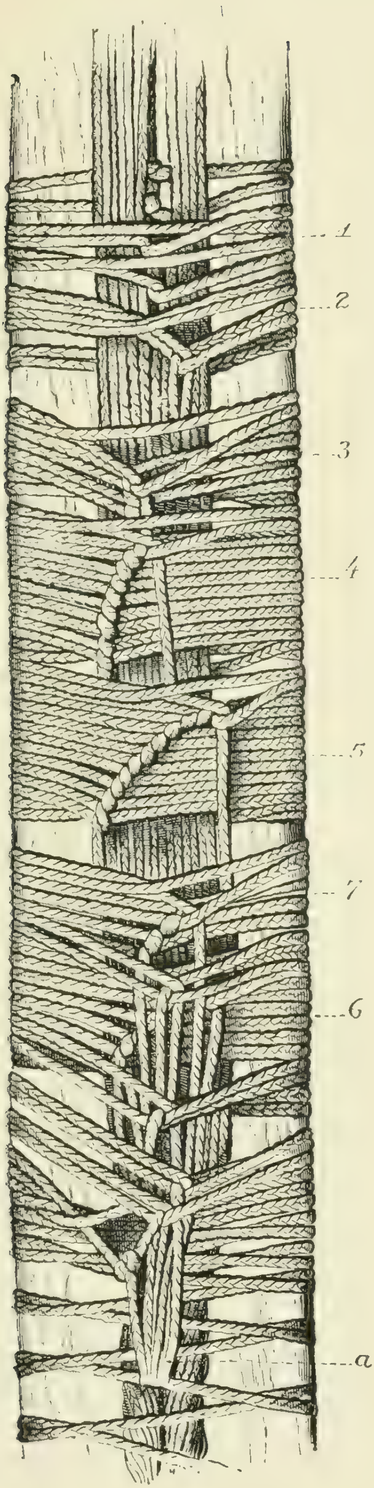
SINEW-BACKED BOWS OF ESKIMO, ARCTIC TYPES.
(After Murdoch.)

EXPLANATION OF PLATE LXIX.

SINEW-BACKED BOWS OF ESKIMO, ARCTIC TYPES.

This plate exhibits the great variety of ways in which the sinew braid is administered upon the bow in the Arctic type for the purpose of minimizing the chances of breaking the very brittle wood of which they are made. The numbers upon the sides of the figures refer to descriptions by Murdoch, in the Report of the U. S. National Museum for 1884.

The first bow upon the plate, Fig. 10, is Cat. No. 89245, U. S. N. M., and the second figure is Cat. No. 72771, U. S. N. M., from Wainwright's Inlet. Collected by U. S. International Polar Expedition.



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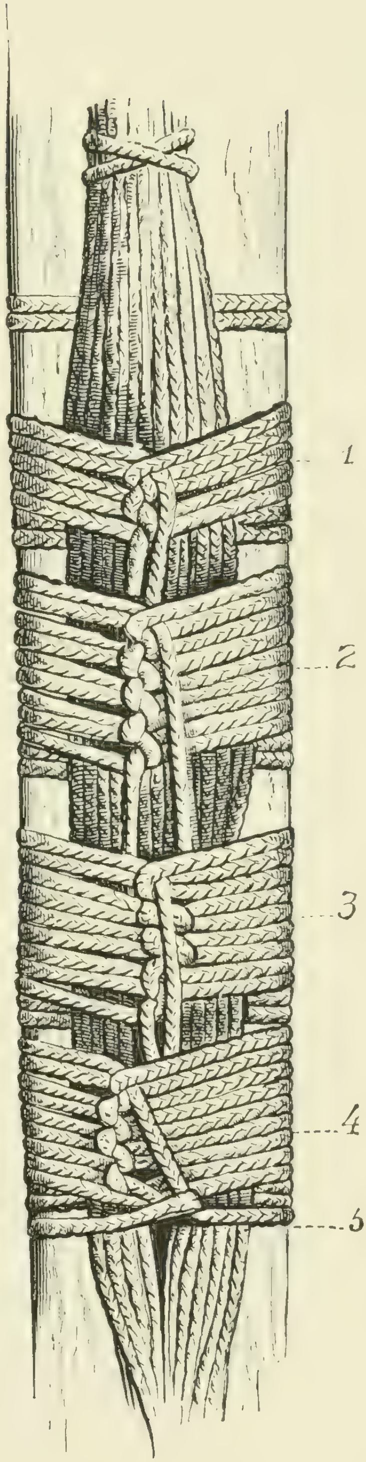


11

SINEW-BACKED BOWS OF ESKIMO, ARCTIC TYPE.

(After Murdoch.)

EXPLANATION OF PLATE LXX.

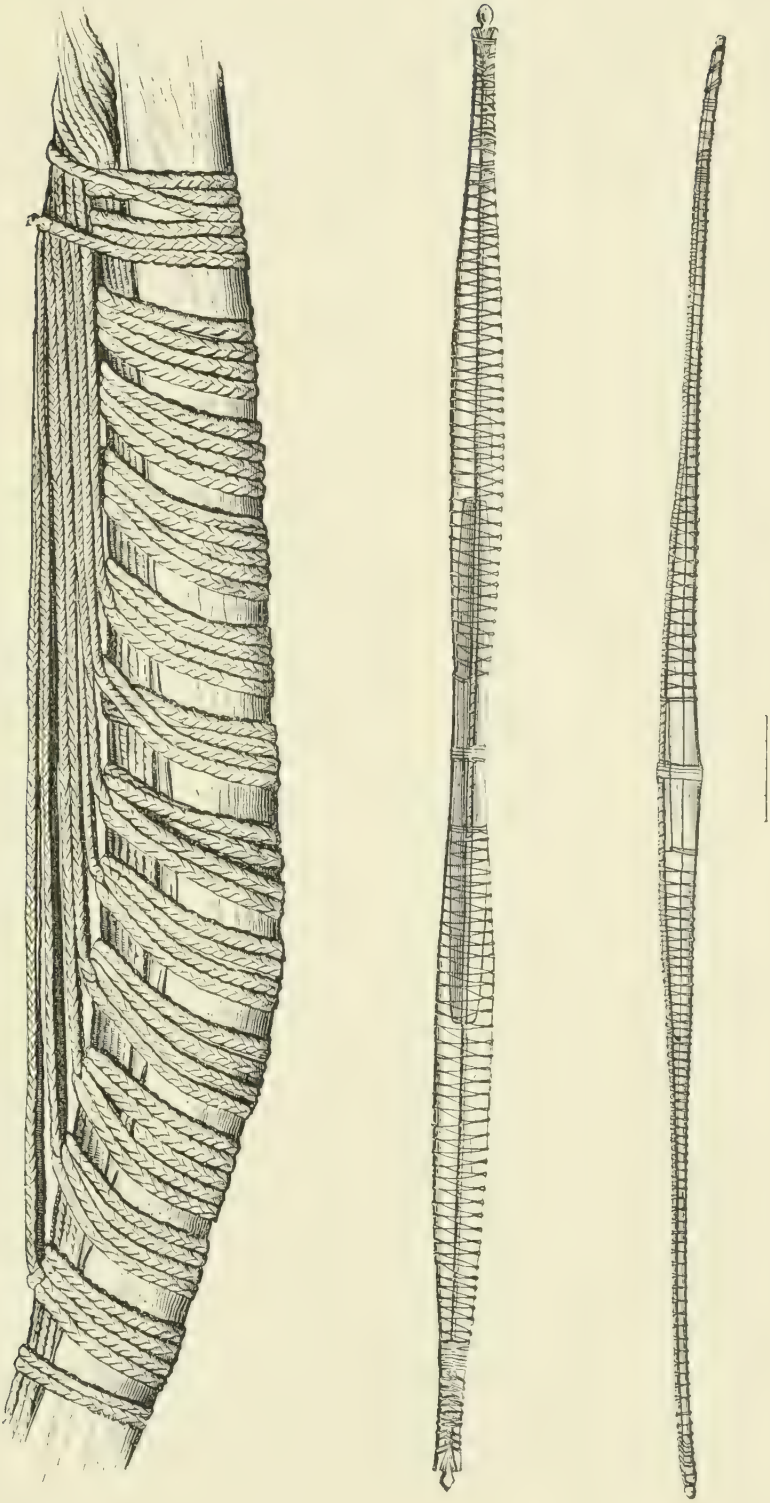
SINEW-BACKED BOWS OF ESKIMO, ARCTIC AND SOUTHERN TYPES.

Upon this plate are represented, first, a section of the Arctic bow to show the method in which short strands at the angles of the bow are administered in order to relieve the strain from the wood.

First figure shows section of Arctic bow 1970, U. S. N. M., from Mackenzie region, collected by B. R. Ross.

The other figure (15), showing back and side, is a bow of the southern type coming from the Yukon Delta and exhibits therefore some of the Arctic characteristics, such as the splint along the grip and the precautions against splitting.

Cat. No. 33867, U. S. N. M. Collected by E. W. Nelson on the delta of the Yukon River.



14 15

SINEW-BACKED BOWS OF ESKIMO, ARCTIC AND SOUTHERN TYPES.

(After Murdoch.)

EXPLANATION OF PLATE LXXI.

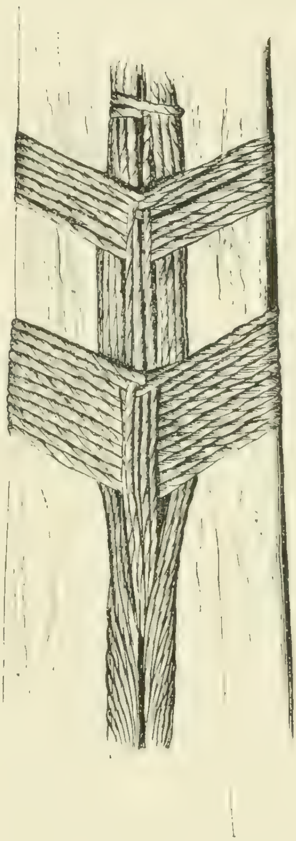
SINEW-BACKED BOWS OF ESKIMO.

The first two figures upon this plate, 16 and 17, illustrate a bow in which the southern type of wood has administered upon it the backing of the Arctic type. The method of administering the short strands by means of half hitches to prevent the splitting of the wood is exhibited in the second drawing, figure 17.

The last two figures upon this plate belong to what Murdoch calls the Western type. Perhaps it might be called the Chukchi type. The most noticeable feature is that the backing does not pass around the nocks at the ends of the bow, but the whole cable is held upon the back by means of a series of half hitches. The wood of the bow is either straight or of Tatar shape.

These examples are Cat. Nos. 8822, from Yukon Delta, figures 16 and 17, collected by W. H. Dall, and 2505 from Siberia, figure 18, collected by the North Pacific Exploring Expedition, U. S. N. M.

16



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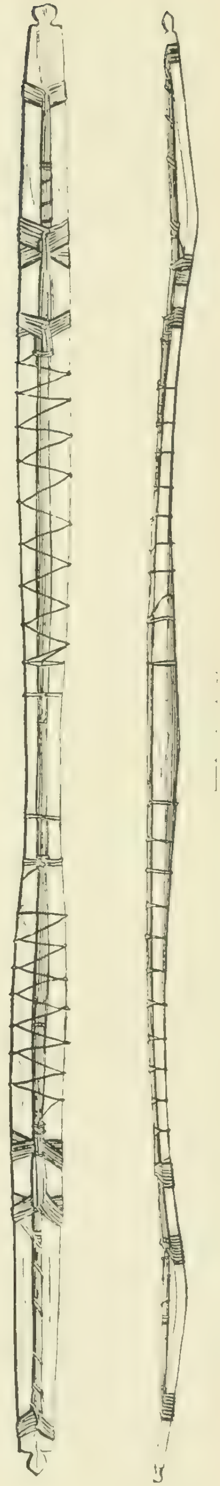


18

SINEW-BACKED BOWS OF ESKIMO, SOUTHERN AND WESTERN TYPE.

(After Murdoch.)

EXPLANATION OF PLATE LXXII.

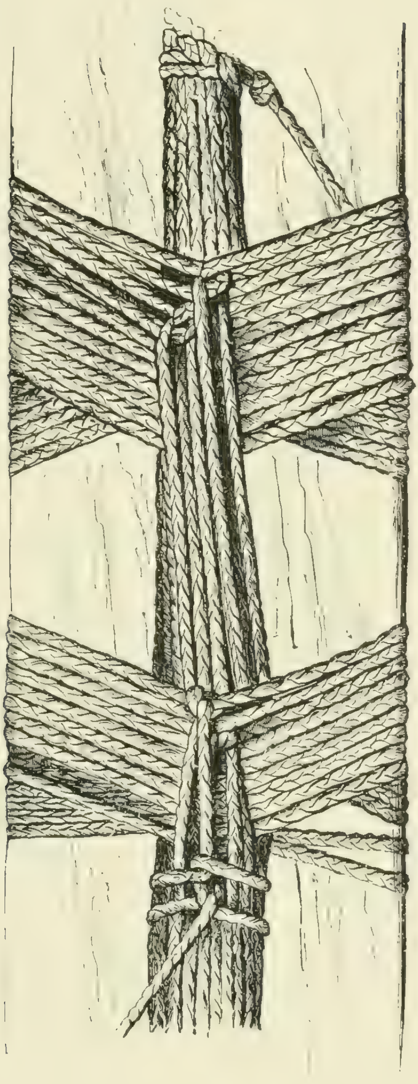
Sinew-Backed Bows of Eskimo, Western Type.

The peculiarities of the bow shown in the last plate and illustrated further on this plate are—

The extensions of their cables, one reaching nearly the whole length of the bow and attached close to the nocks, a second one further down upon the limbs, and a third one from the middle of the limbs. Between these two last-named points all the three cables are united into one passing across the grip.

This figure shows a portion of the first cable (the longest cable), the passing in strands of the second and third cables, and the union of all three into one. The second figure upon this plate (fig. 21) is a straight bow upon which the backing has upward of seventy strands twisted into three cables of Arctic type. In this example also, the longest cable passes around the nocks.

Section of Cat. No. 2505, U. S. N. M., and 2508, Eastern Siberia, collected by North Pacific Exploring Expedition.



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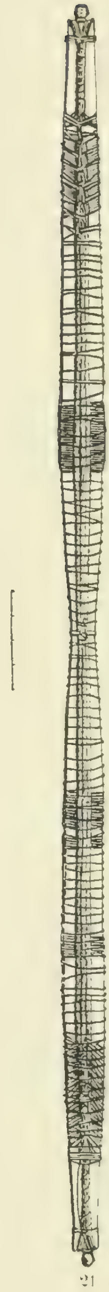
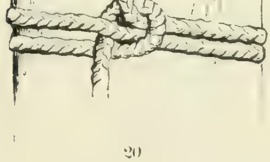


21



20

SINEW-BACKED BOWS OF ESKIMO, WESTERN TYPE.

(After Murdoch.)

EXPLANATION OF PLATE LXXIII.

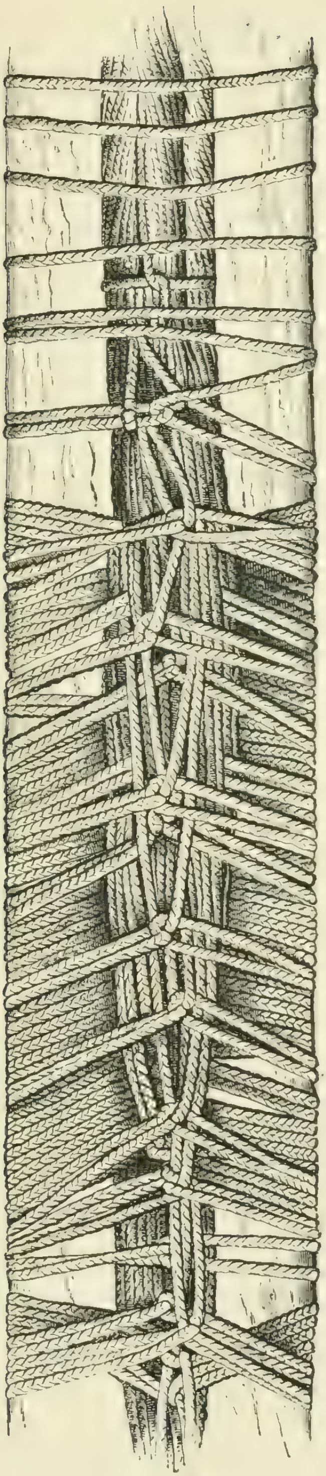
SINEW-BACKED BOWS OF ESKIMOS, MIXED TYPES.

The first figure upon this plate exhibits the methods of seizing and the variety of attachments in passing the braided cord from the function of wrapping the bow on to the function of strand in the treble cable on the back. With a little patience it is easy to trace with the eye each braid strand from one function to the other.

The last two figures upon this plate represent a bow in which the backing is of the Arctic type and the shape of the bow approaches the Western type.

The first figure is Cat. No. 2505, U. S. N. M.

Second, Cat. No. 2506, E. Siberia. Collected by Northern Pacific Exploring Expedition.



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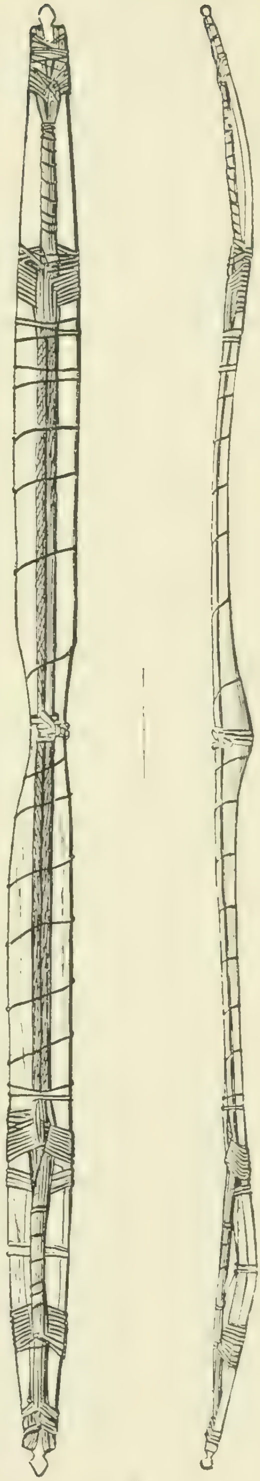


23

SINEW-BACKED BOWS OF ESKIMO, MIXED TYPES.

(After Murdoch.)

EXPLANATION OF PLATE LXXIV.

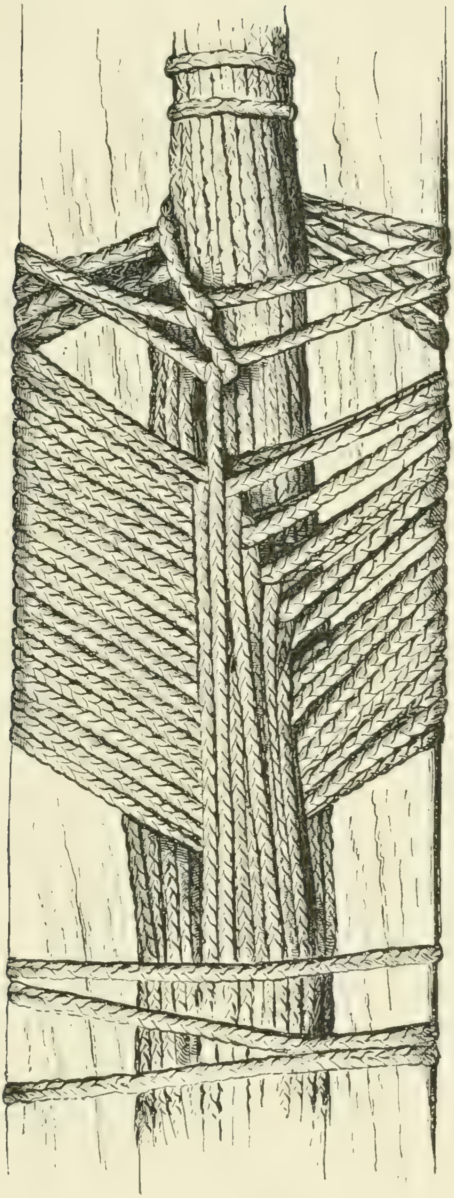
Sinew-Backed Bows of Eskimo.

The principal figure upon this plate shows the administration of the braided line just at the point where the third cable coming from the nock crosses the bend in the bow. It is at this point that the greatest strain occurs and there is more pressing need for additional protection. Of this bow Murdoch says that "it approaches very close to the Arctic type, but shows traces of the Western model in having the ends of the long strands stretched across the bend and one single short strand returning to the tip from beyond the bend, while a fourth is precisely of the Arctic type, with a very large number of strands." The ivory levers shown upon the plate have been described, and are used in Cat. Nos. 2506 and 89466, U. S. N. M.

Figures 25 and 26 illustrate a peculiar "clove hitch" and "soldier's hitch" employed in this example.

Point Barrow. Collected by U. S. International Polar Expedition.

PLATE LXXIV.



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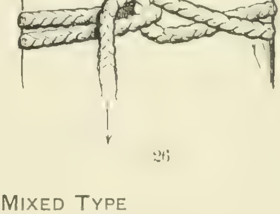


26

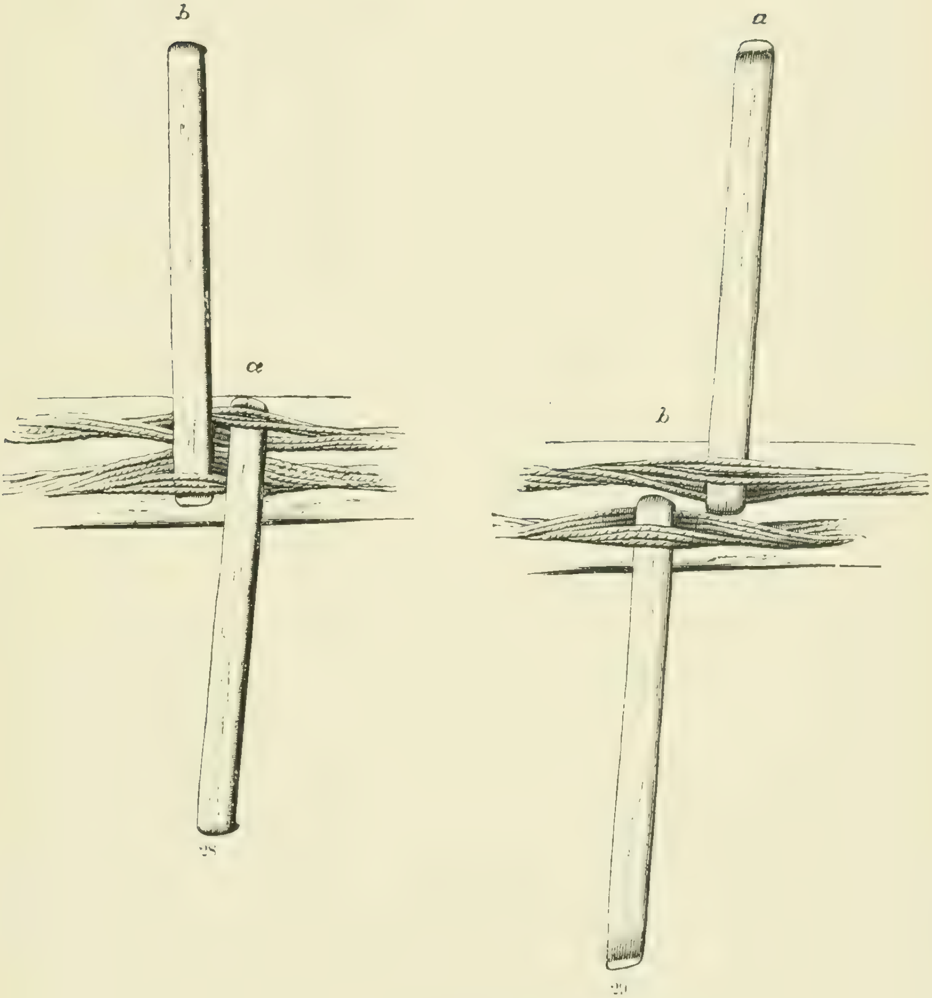
SINEW-BACKED BOWS OF ESKIMO, MIXED TYPE

(After Murdoch.)

EXPLANATION OF PLATE LXXV.

Twisting Levers for Sinew-Backed Bows of Eskimo.

This plate shows the manner in which the ivory levers are used in winding up the double cable on the back of an Eskimo bow. It will be seen that each lever has a hook at each end, but on alternate sides. The end of each lever is thrust through the middle of a loose cable, hook side downward. It is then revolved through half a circle, as far as it will go, then pushed its entire length, which brings the hook at the other end in place for another half turn, and so on. A rawhide string is passed through both cables, wrapped about the grip and made fast. This prevents the cables from unwinding while the bow is in use.



TWISTING LEVERS FOR SINEW-BACKED BOWS OF ESKIMO.
(After Murdoch.)

EXPLANATION OF PLATE LXXVI.

A MAP TO ILLUSTRATE THE DISTRIBUTION OF ESKIMO BOWS.

Prepared by John Murdoch to show the distribution of the three types of bows in Alaska. In "A Study of the Eskimo Bows in the U. S. National Museum," Report of the U. S. National Museum, 1884.

In the plan—

A. stands for Arctic type.
S. stands for Southern type.
W. stands for Western type.

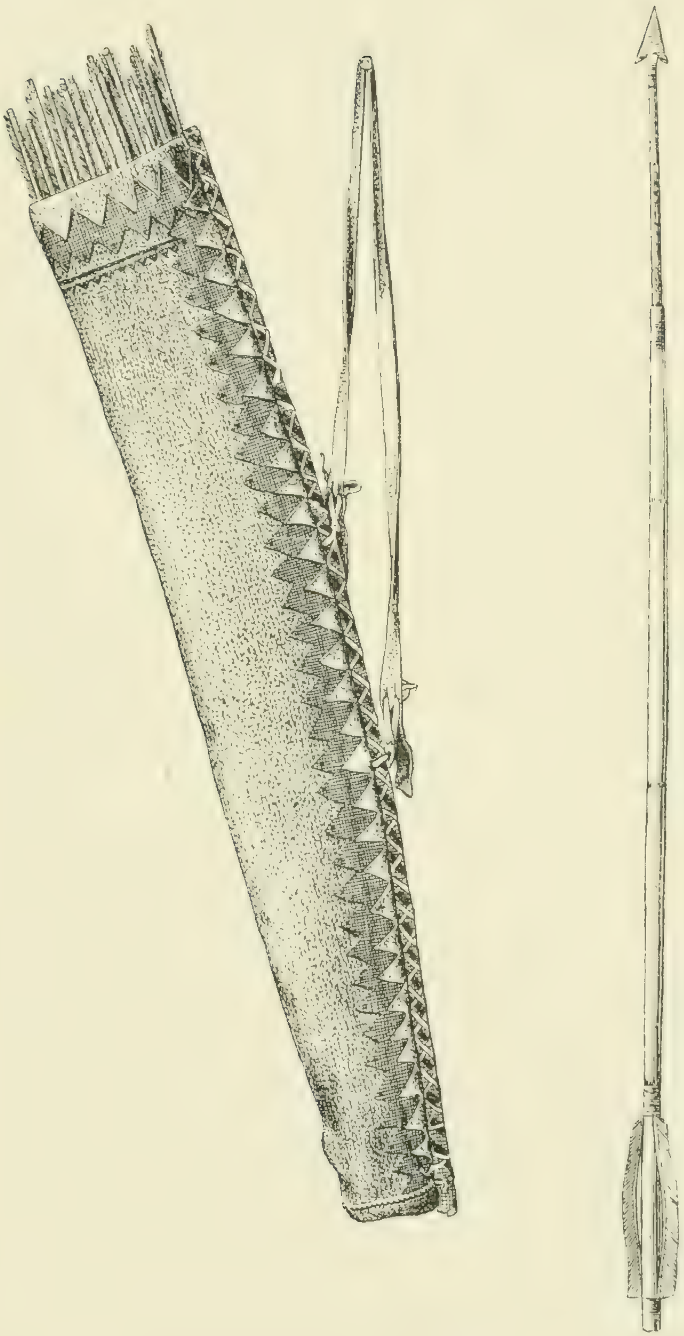

Arctic Ocean.
Pt. Barrow. A
Wainwright's Inlet A
Mackenzie R. A
Pt Hope A
Kotzebue Sd. A. ?
Siberia W. (& A.)
Kaviak Pen. A.?
St. Lawrence Id. W.
Norton Sd. A & S.
Yukon R. A & S.
C. Romanzoff S.
Kuskoquim S.
Nunivak Id. S.
Bering Sea
Bristol Bay
Kadiak Id. S
Seal Ids.
Gulf of Alaska.
Aleutian Ids.
MAP
TO SHOW THE DISTRIBUTION OF THE
Eskimo Bows.
A. Arctic Type
S. Southern Type
W. Western Type.

EXPLANATION OF PLATE LXXVII.

Apache Arrow Case and Arrow.

Fig. 1. Quiver, deerskin, smoke-tanned; bow case wanting. Arrow case, long tapering sack, stiffened at the back by means of a rod of wood sewed on with buckskin string. Decorated along the back and around the margins with scallops cut in red flannel and skin. A narrow band of exactly the same pattern is painted down the outside, directly opposite and around the upper margin. Bandolier, simple string of buckskin attached to stiffener. Filled with typical reed-shaft arrows, with hardwood twig foreshafts and iron points, as shown on the right of the quiver. Length, 35 inches.

Cat. No. 21515, U. S. N. M. Apache Indians, Athapascan stock, Arizona. Collected by J. B. White, U. S. Army.



APACHE ARROW-CASE AND ARROW.

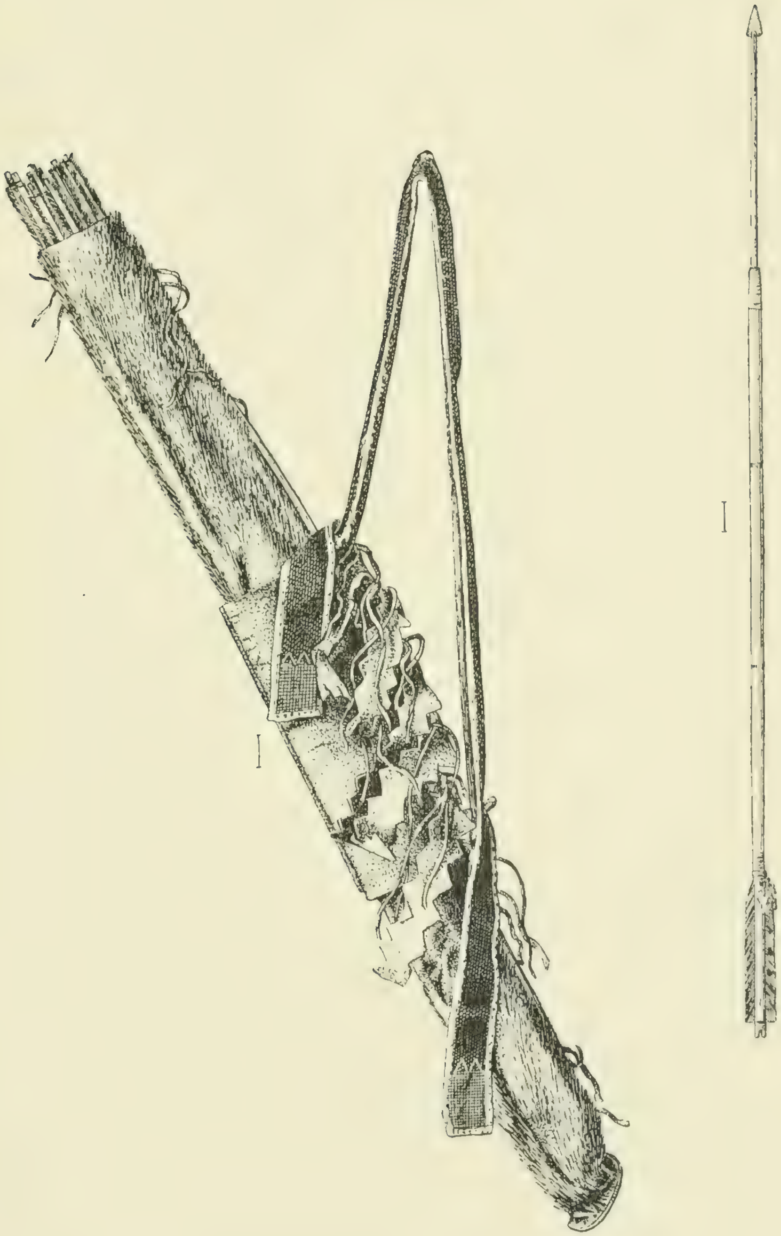
EXPLANATION OF PLATE LXXVIII.

APACHE ARROW CASE AND ARROW.

FIG. 1. QUIVER, deerskin. Bow case, none. Arrow case, bag with a stiffener of wood attached by means of strings along the seam. About the middle of the quiver is a band of smoked deerskin leather, with a fringe characteristic of the tribe, in which the scallop before mentioned appears. The bandolier is a strip of cotton cloth and blue flannel. Length of quiver, 34 inches.

Cat. No. 17331, U. S. N. M. Apache Indians, Athapascan stock, Arizona. Collected by Dr. H. C. Yarrow, U. S. Army.

NOTE.—The arrows accompanying this quiver, of which an example is given, are of the characteristic Apache type, shaft of reed, foreshaft of hardwood, points of iron. The extra length of the quiver is due to the fact that the reed arrows are longer than those with shafts of hard wood.



APACHE ARROW-CASE AND ARROW.

EXPLANATION OF PLATE LXXIX.

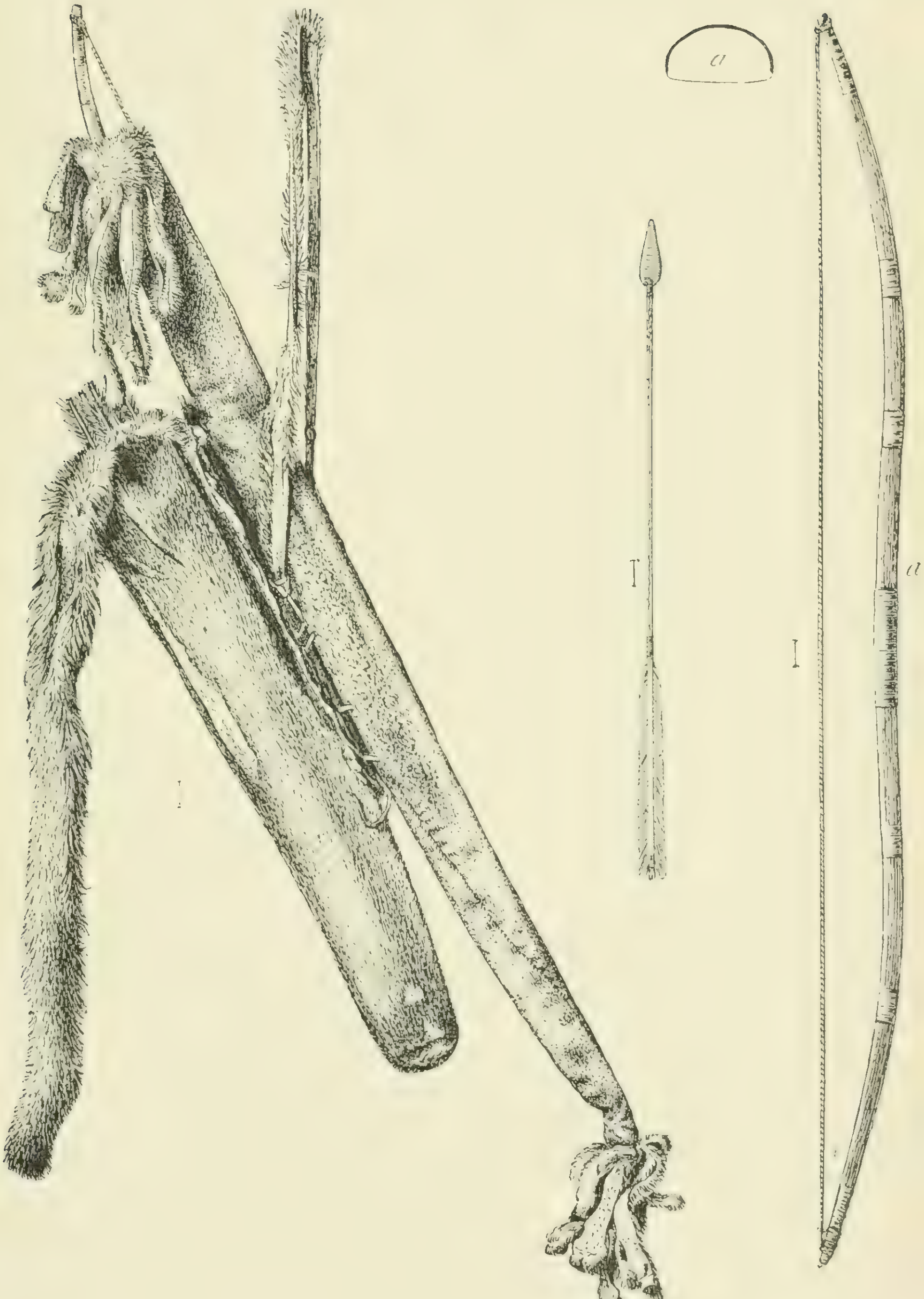
NAVAJO QUIVER, SINEW-LINED BOW AND ARROW, ALL OF NORTHERN TYPE.

FIG. 1. QUIVER, mountain lion skin. Bow case made with hair side inward; arrow case, hair side outward. There is also between the two, where they are joined, a stiffener of wood, which belongs especially to the arrow case, showing that the bow case is an afterthought. For decoration the ends of the bow case are adorned with a fringe of lion skin, and from the top of the arrow case the tail of the lion depends. Length: bow case, 44 inches; arrow case, 28 inches.

Cat. No. 76684, U. S. N. M. Navajo Indians, Athapascan stock, Arizona. Collected by Dr. Washington Matthews, U. S. Army.

FIG. 2. BOW, made of mesquit wood, rounded on the back and oval in form, lined with sinew, which is strengthened by three bands of sinew. The grip is seized with a delicate wrapping of buckskin string. The ends of the horns of the bow are wrapped with sinew and there is no especial modification of the ends for receiving the string. The bowstring is of two-ply twine, sinew cord. Length, 3 feet 11 inches. The Tacullies or Carriers of British Columbia, the Hupa of northern California, and the Navajo of Arizona, all Athapscans, use the sinew-lined bow.

Cat. No. 76684, U. S. N. M. Navajo Indians, Athapascan stock, Arizona. Collected by Dr. Matthews.



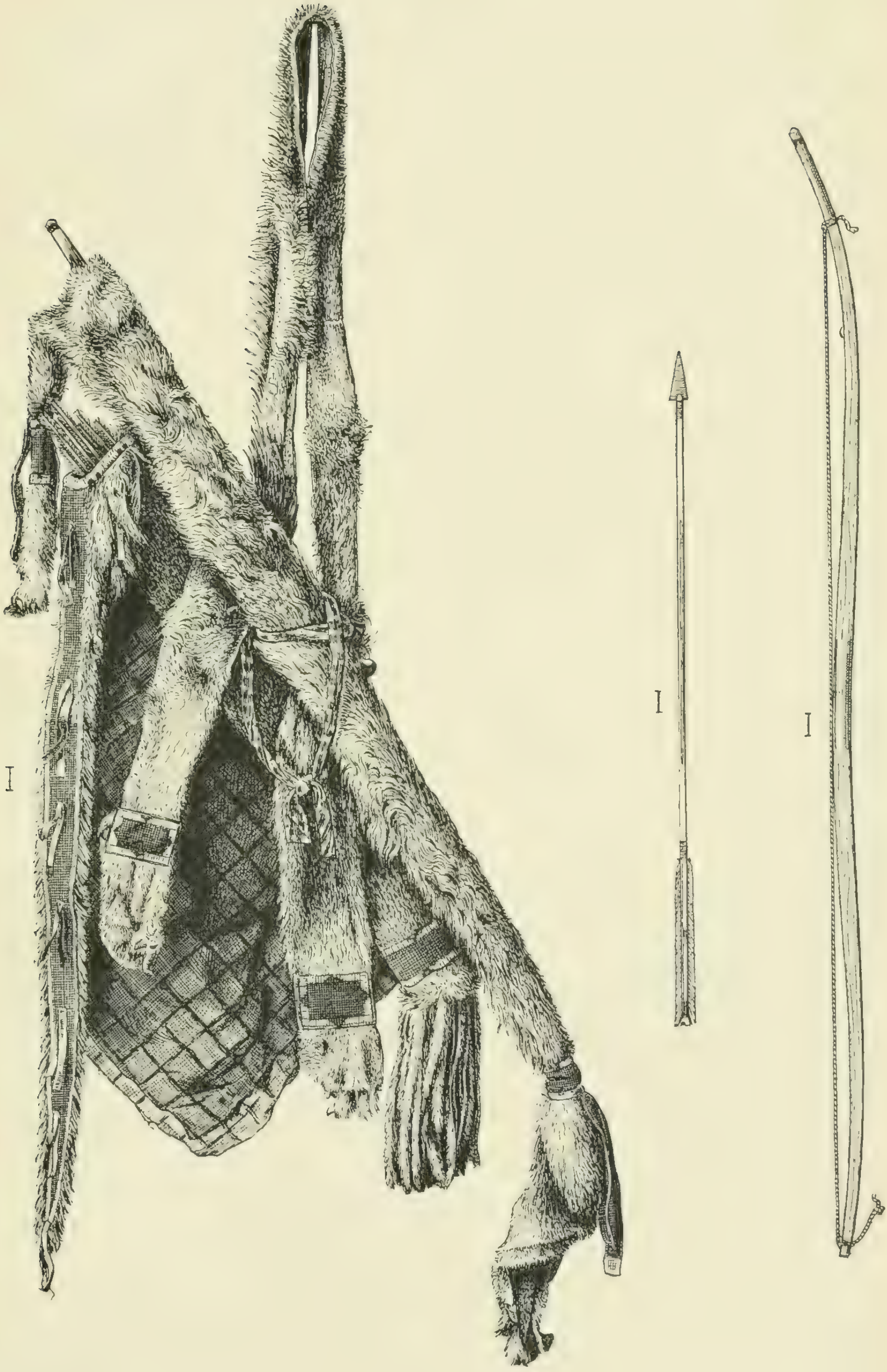
NAVAJO QUIVER, SINEW-LINED BOW AND ARROW, ALL OF NORTHERN TYPE.

EXPLANATION OF PLATE LXXX.

CHEYENNE QUIVER, SELF BOW AND ARROW, WITH SHAFT GROOVES.

FIG. 1. QUIVER, mountain lion skin. Bow case and arrow case separate. Both made with hair outward, and ornamented with fringes. From the bottom of the bow case depends one of the feet of the lion with claws. At the bottom is another foot of the lion wrapped with a red flannel cloth and slightly decorated with beads. Arrow case fringed at the top and bottom with strips of hide, and with a long pendant from the upper border made of the lion's tail, faced with red flannel and decorated with beadwork and ribbon. A unique attachment to this quiver is a streamer consisting of one and a half yards of red and black calico sewed to the inner lining of the arrow case. Bandolier, of lion skin faced with tent cloth (cotton duck). The bow shown in the plate with its arrow is of the form common throughout the Plains of the Great West. It is made of ash, and has a slight double curve. Length: bow case, 40 inches; arrow case, 25 inches.

Cat. No. 129873, U. S. N. M. Cheyenne Indians, Algonquian stock. Collected by H. M. Creel, U. S. Army.



CHEYENNE QUIVER, SELF BOW AND ARROW WITH SHAFT GROOVES.

EXPLANATION OF PLATE LXXXI.

CHIPPEWA SELF BOW, ARROW, AND QUIVER.

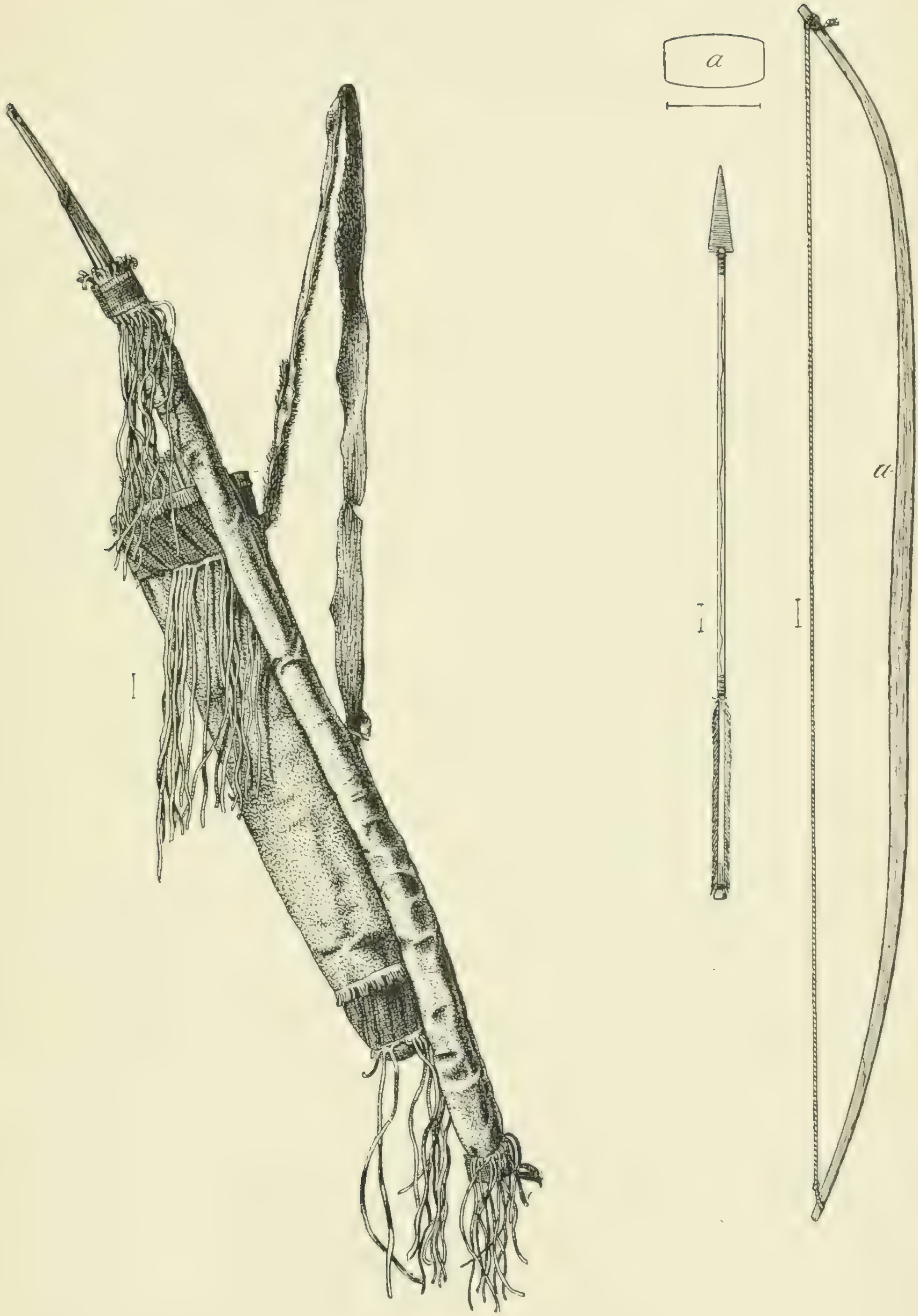
FIG. 1. BOW, nearly rectangular in section, tapering toward the end; slightly double curve. One notch at each end and both on the same side of the bow for receiving the string, which is a 2-ply twine. Length: 3 feet 9 inches.

Cat. No. 9063, U. S. N. M. Chippewa Indian. Algonquian, Dakota. Collected by Dr. W. H. Gardner, U. S. Army

FIG. 2. QUIVER, dressed buffalo hide. Bow case is a long narrow sack, fitting bow; arrow case, wide bag tapering toward the bottom. Both ornamented slightly with fringe of rawhide, beads, and red flannel. The bandolier is a narrow band of buffalo skin with the hair on. Length: bow case, 38 inches; arrow case, 24 inches.

Cat. No. 9063, U. S. N. M. Chippewa, Algonquian stock, Dakota. Collected by U. S. War Department.

NOTE.—The Chippewa Indians are more civilized than their neighbors, and this specimen shows a degenerate style of doing their own work, and much borrowing from the whites. The arrow is of the common Plains type.



CHIPPEWA SELF BOW, ARROW, AND QUIVER.

EXPLANATION OF PLATE LXXXII.

KIOWA QUIVER CONTAINING BOWS AND ARROWS IN THEIR CASES, FIRE BAG, AND AWL CASE.

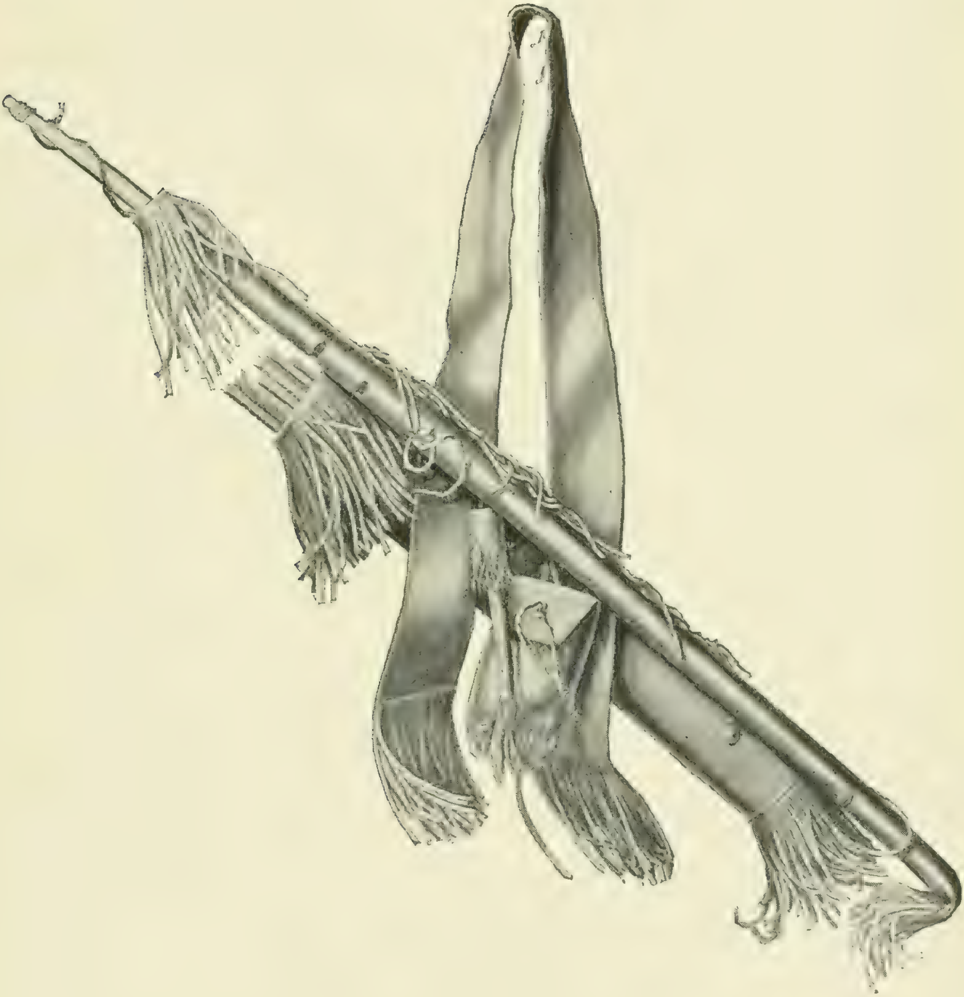
FIG. 1. QUIVER, harness leather. The bow case is a long slender bag just fitting the bow; the arrow case is a broad bag—both fringed at the bottom by cutting pieces of leather into strings. The two pieces are attached at the margins with buckskin strings. Bandolier is a broad strip of rawhide. The bottoms and upper margins of the bow case and quiver, the awl case, the end of the bandolier, and the bottom of the tool bag are decorated with leather cut in fringes. Length of the bow case, 44 inches; arrow case, 20 inches.

Cat. No. 152895, U. S. N. M. Kiowa Indians, Kiowan stock. Collected by James Mooney.

FIG. 2. BOW, made of Osage orange. It is rounded on the back and inside, and square on the sides. Largest at the grip and tapering along the limbs toward the ends. The notches for the bowstring are cut in on alternate sides near the end. The bowstring is made of 4-ply sinew cord. Double curve. Length: 4 feet 4 inches.

Cat. No. 152895, U. S. N. M. Kiowa Indians, Kiowan stock, Indian Territory. Collected by Jas. Mooney.

This is a complete archery outfit. The bow case, arrow case, tool bag, and awl case are separate. The bow is made of Osage orange. The bowstring is of 4-ply twine or sinew cord; the arrows are of the original Plains type. Shaft of hard wood, worked down with straight shaft streaks.



KIOWA QUIVER CONTAINING BOW AND ARROWS IN THEIR CASES FIRE BAG AND AWL CASE.

EXPLANATION OF PLATE LXXXIII.

DAKOTA QUIVER, SELF BOW AND ARROW, WITH SHAFT GROOVES.

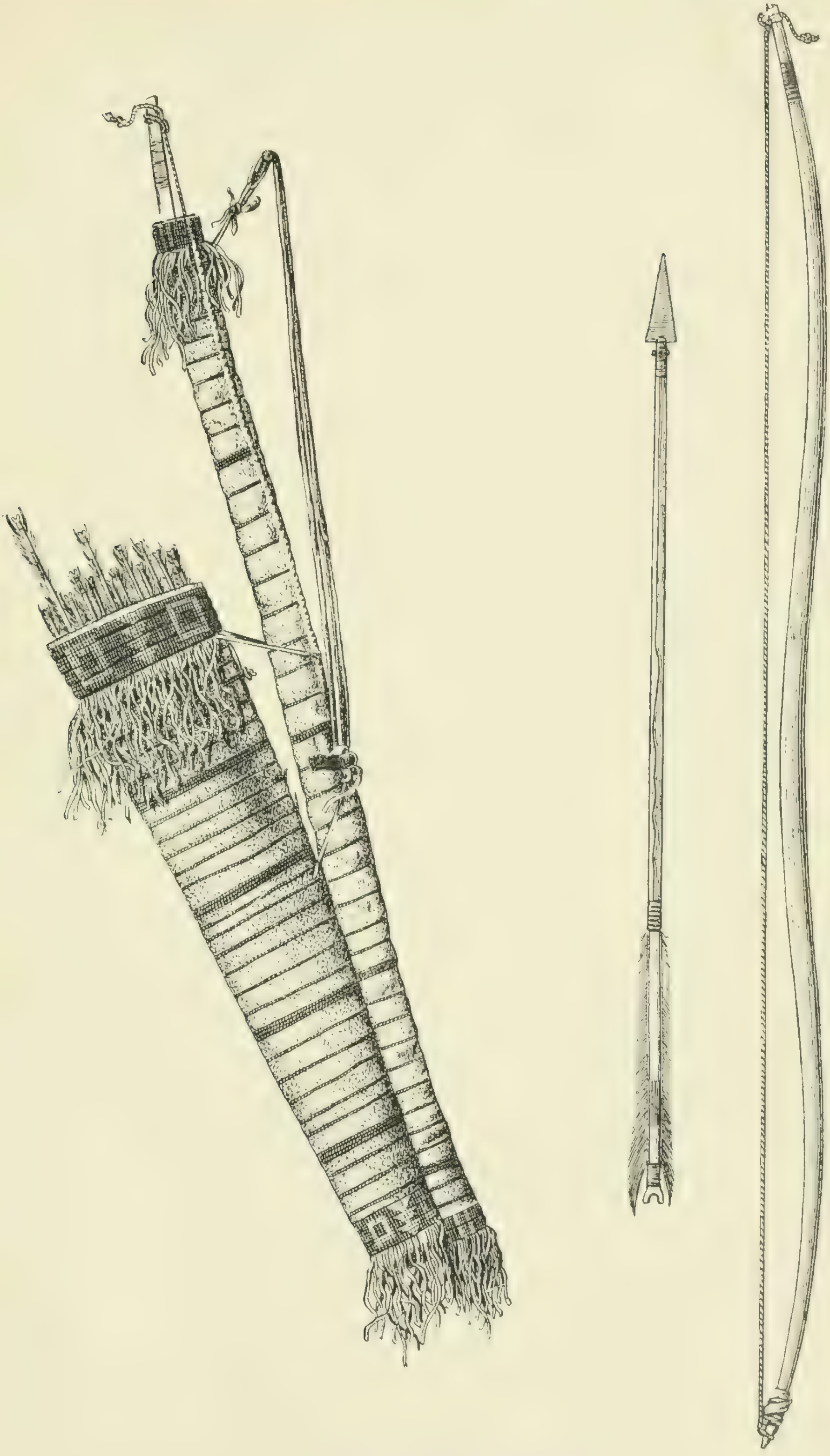
FIG. 1. BOW, hickory, rectangular in section, double curve, tapering toward the ends. Two notches at one end, and one at the other for receiving the string, which is a 2-ply twine of sinew. Length: 3 feet 7 inches.

Cat. No. 131356, U. S. N. M. Sioux Indians, Siouan stock, Dakota. Collected by Mrs. A. C. Jackson.

FIG. 2. QUIVER, made of dressed buffalo hide. Bow case and arrow case separate. The former, a long narrow bag; the latter, a short sack, slightly tapering toward the bottom. Both are ornamented with rings of bird quill whipped on closely; the upper borders and the ends ornamented with finely-cut fringe. The bow case and outside sacks, top and bottom, decorated with patterns in beadwork. Length: bow case, 38 inches; arrow case, 24 inches.

Cat. No. 131356, U. S. N. M. Sioux Indians, Siouan stock, Upper Missouri. Collected by Mrs. A. C. Jackson.

The noticeable points on the arrow are the sinuous shaft streaks, the dainty feathering projecting behind the nock and the flaring nock, which gives a perfect grip for the thumb and forefinger in the shooting by primary or secondary release.



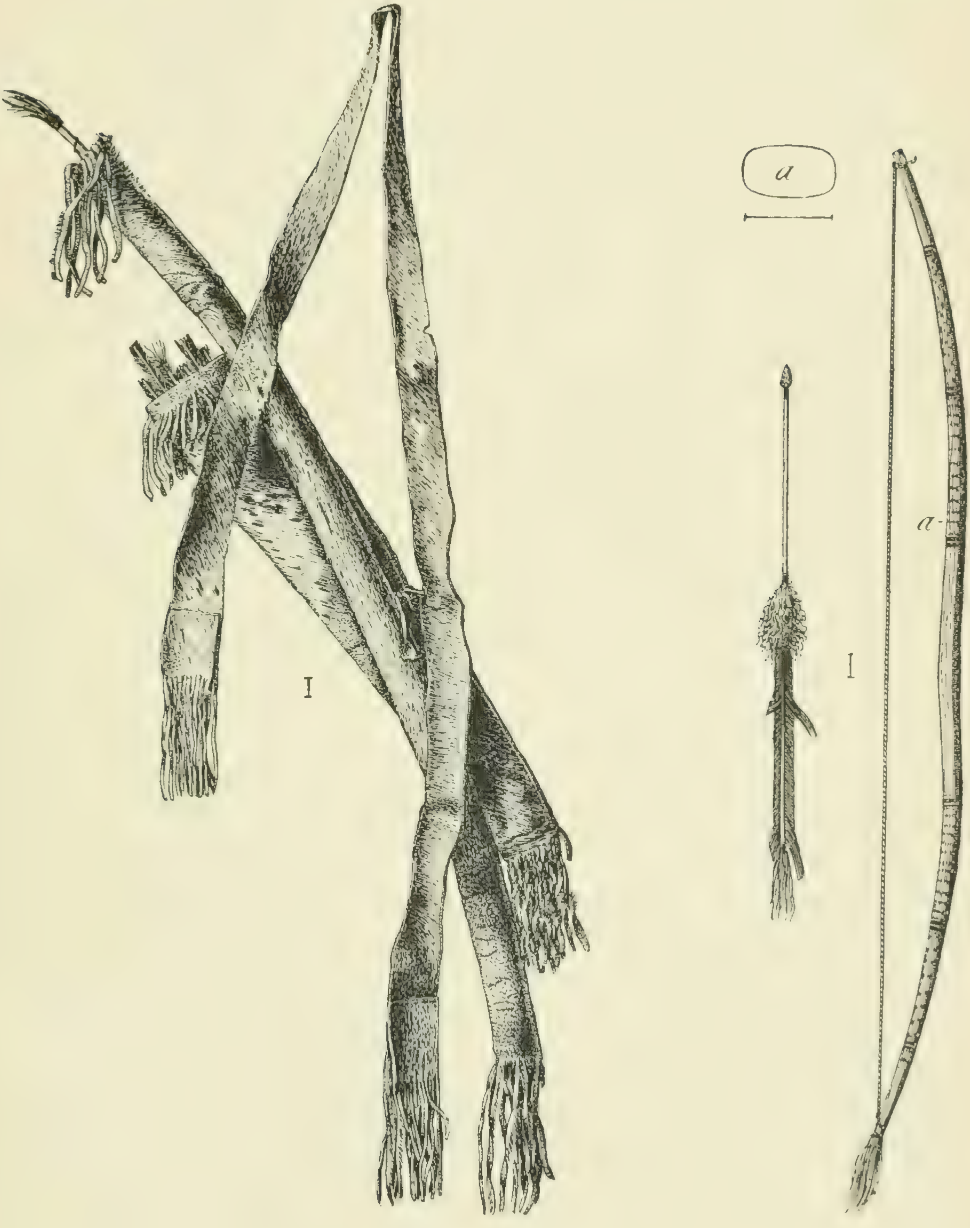
DAKOTA QUIVER, SELF BOW, AND ARROW WITH SHAFT GROOVES.

EXPLANATION OF PLATE LXXXIV.

SIOUX QUIVER, MADE OF COW SKIN, ARROW AND BOW.

FIG. 1. QUIVER, mottled cow skin. Bow case and arrow case are made after the usual pattern, ornamented at the top and bottom with fringes of hide with the hair on, and joined together by their margins. Bandolier of a strip of hide with fringes at the end. Length of bow case, 43 inches; arrow case, 26 inches.

Cat. No. 154016, U. S. N. M. Sioux Indians, Siouan stock, Dakota. Collected by Gen. Hazen, U. S. Army.



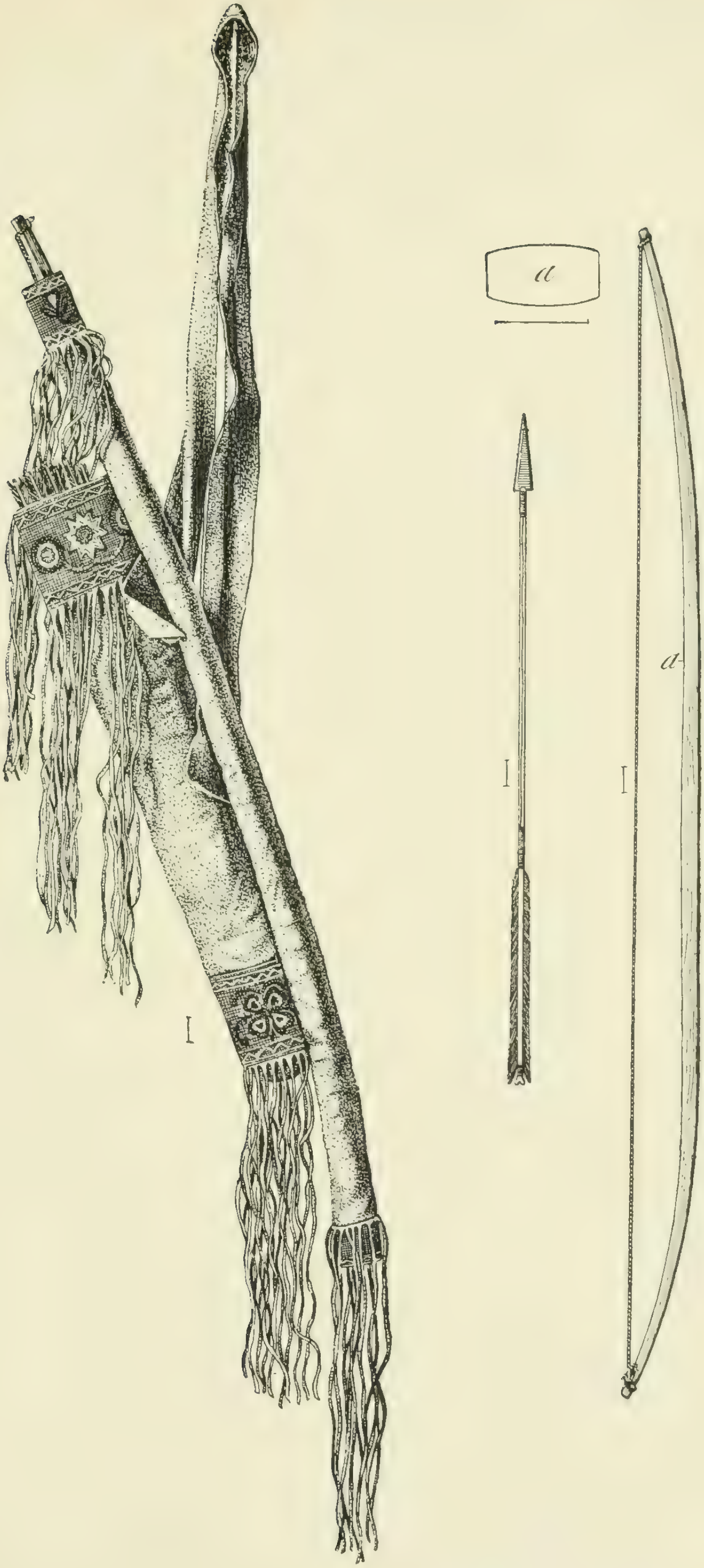
SIOUX QUIVER, MADE OF COWSKIN, ARROW, AND BOW.

EXPLANATION OF PLATE LXXXV.

DAKOTA QUIVER, SELF BOW AND ARROW, WITH STRAIGHT SHAFT GROOVE.

FIG. 1. QUIVER, of buffalo skin; bow case and arrow case separate. Bow case, a narrow bag just fitting the bow. Arrow case, a wide sack tapering toward the bottom. Both cases adorned at upper and lower margins with long fringes of buckskin, at the head of which is a band of red flannel decorated with "white-man's" patterns in beadwork. Bandolier is a strip of buffalo skin with hair left on. The bow and arrows are of the universal Siouan type. Length of bow case, 42 inches; arrow case, 26 inches.

Cat. No. 23735, U. S. N. M. Sioux Indians, Siouan stock, Dakota. Collected by Paul Beckwith.



DAKOTAN QUIVER, SELF BOW, AND ARROW WITH STRAIGHT SHAFT GROOVE.

EXPLANATION OF PLATE LXXXVI.

TONKAWA.

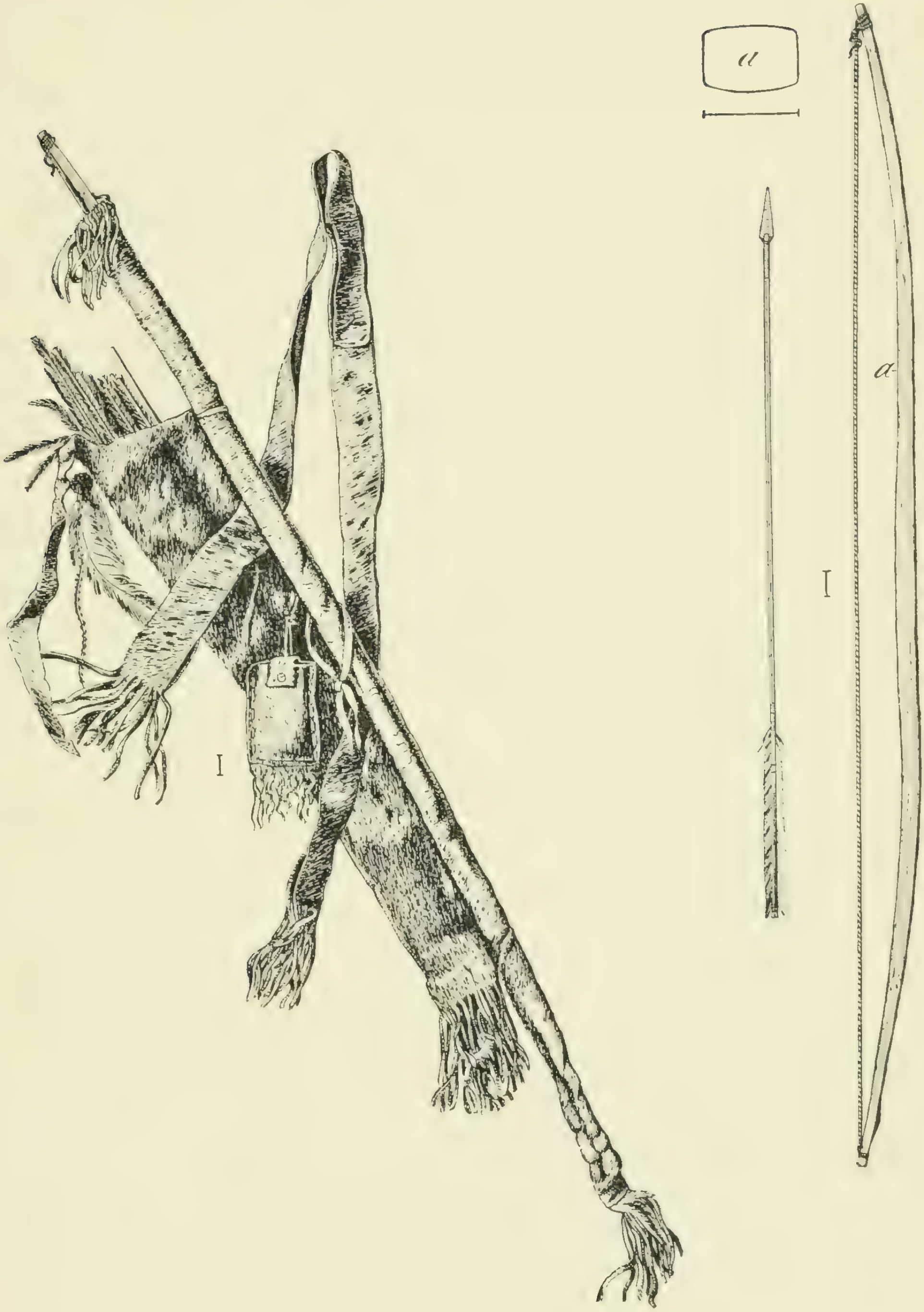
FIG. 1. QUIVER, made of cow skin; bow case of mottled cow skin with the hair left on, forming a long close sack. The arrow case is a short, wide sack. Bandolier, broad strip of cow skin. From the ends of bow case, arrow case, and bandolier fringes of cut skin depend. The bow case and arrow case are sewed together at the margins or raw edges so that in the completed quiver the seams turn inward and are largely concealed. The tool bag is of rawhide and, singularly enough, contains a flint and steel and a powder charger made of the top of a buffalo horn. Length of bow case, 48 inches; arrow case, 28 inches.

Cat. No. 8448. U. S. N. M. Tonkawa Indians, Tonkawan stock, Texas. Collected by H. McElderry, U. S. Army.

NOTE.—After the Government entered into a treaty with the Indian tribes, among the annuities were cattle, and from that time cow skin very largely took the place of other hides in the making of quivers along the Plains of the great West, where buffalo and deer were less abundant. Numbers of Siouan, Caddoan, Kiowan, Algonquian, Shoshonean, and Tonkawan tribes, all made their quivers of cow skin, either with the hair left on or tanned. The bow case and the arrow case were made after the general plan of the example here described.

FIG. 2. BOW, hard wood, hickory, the natural surface of the wood on the back. Section nearly square, tapering slightly toward either end. Notch single on alternate sides. Bowstring of 4-ply twine. Bow has a single curve. Length: 3 feet 11 inches. The arrow is of the Plains type, showing that region and game override social and other anthropological distinctions.

Cat. No. 8448. U. S. N. M. Tonkawa Indians, Caddoan stock, Texas. Collected by H. McElderry, U. S. Army.



Tonkawa.

EXPLANATION OF PLATE LXXXVII.

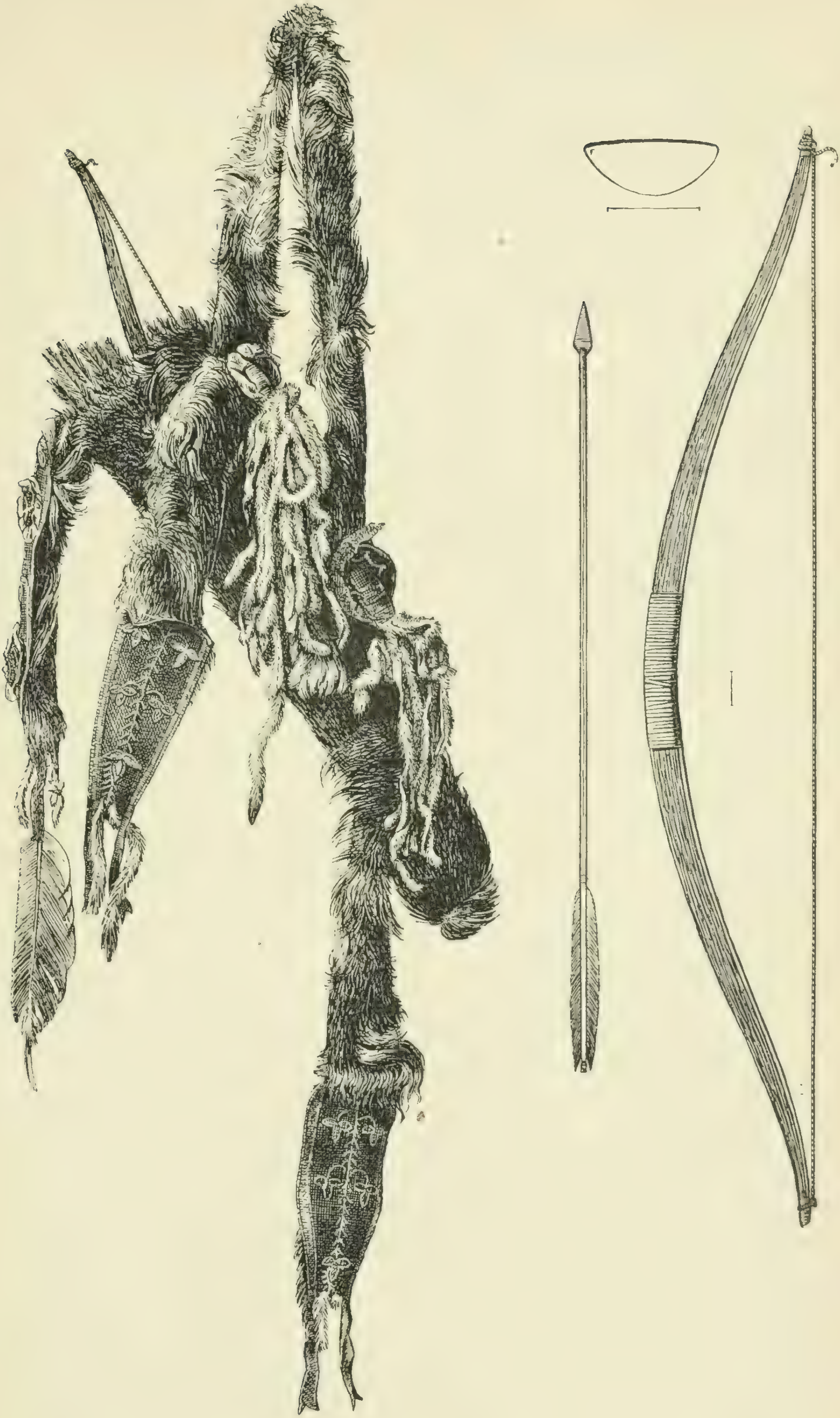
SHOSHONEAN QUIVER, PLAIN ARROW WITH SHAFT GROOVES, AND SINEW-LINED BOW OF CALIFORNIA TYPE.

FIG. 1. QUIVER, black bear skin, with hair left on; bow case and arrow case separate. The ornaments are tassels of ermine skin hanging from the ends of the bandolier, and long flaps of bearskin, lined on the outside with green cloth and decorated with beadwork, ribbon, and gull feathers. The patterns on the green cloth are copied from those of the whites. Length of bow case, 41 inches; arrow case, 27 inches.

Cat. No. 9044, U. S. N. M. Snake Indians, Shoshonean stock, Idaho. Collected by Dr. S. Wagner.

FIG. 2. BOW, said to be Snake Indian bow from Idaho, but it belongs to the broad variety of sinew-lined bows of California. If used by the Snake Indians it has been introduced as a matter of trade. The nocks are simply tapering at the ends and no provisions for the bowstring, which is simply caught over the tapering ends. Same as 19322. Length: 3 feet 4 inches.

Cat. No. 9044, U. S. N. M. Snake Indians, Shoshonean stock, Idaho. Collected by Dr. C. Wagner, U. S. Army.



SHOSHONEAN QUIVER, PLAIN ARROW WITH SHAFT GROOVES, AND SINEW-LINED BOW OF CALIFORNIAN TYPE.

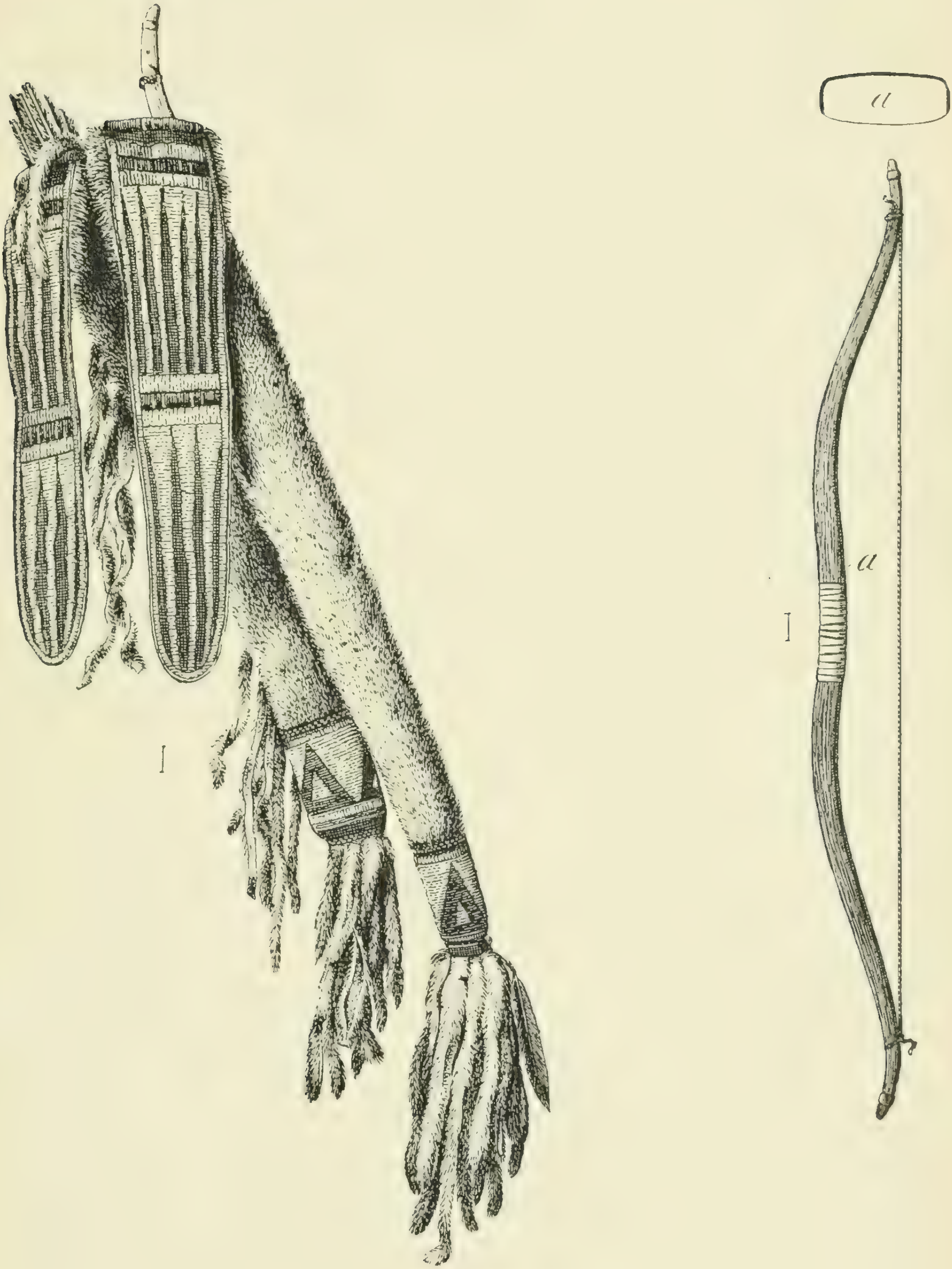
EXPLANATION OF PLATE LXXXVIII.

Nez Percé Quiver and Bow.

Fig. 1. Quiver, of beaver skin; bow case and arrow case made separately of beaver skin with the hair side out. Ornamented at the bottom with tassels of strips of skin, bird feathers and little bells, and with bands of beadwork, and at the top with rings of beadwork and long flaps of beaver skin, lined with red flannel and decorated with beadwork. Bandolier missing. Length of bow case, 33 inches; arrow-case, 27 inches.

Cat. No. 23843, U. S. N. M. Nez Percé Indians, Shahaptian stock, Idaho. Collected by J. B. Monteith.

Note.—Tribes of the Shahaptian stock displayed a great deal of taste in all of their work, and some of the quivers from that region which are accredited to the Shoshonean and Salishan tribes have undoubtedly been made under the influence of these Indians.



NEZ PERCÉ QUIVER AND BOW.

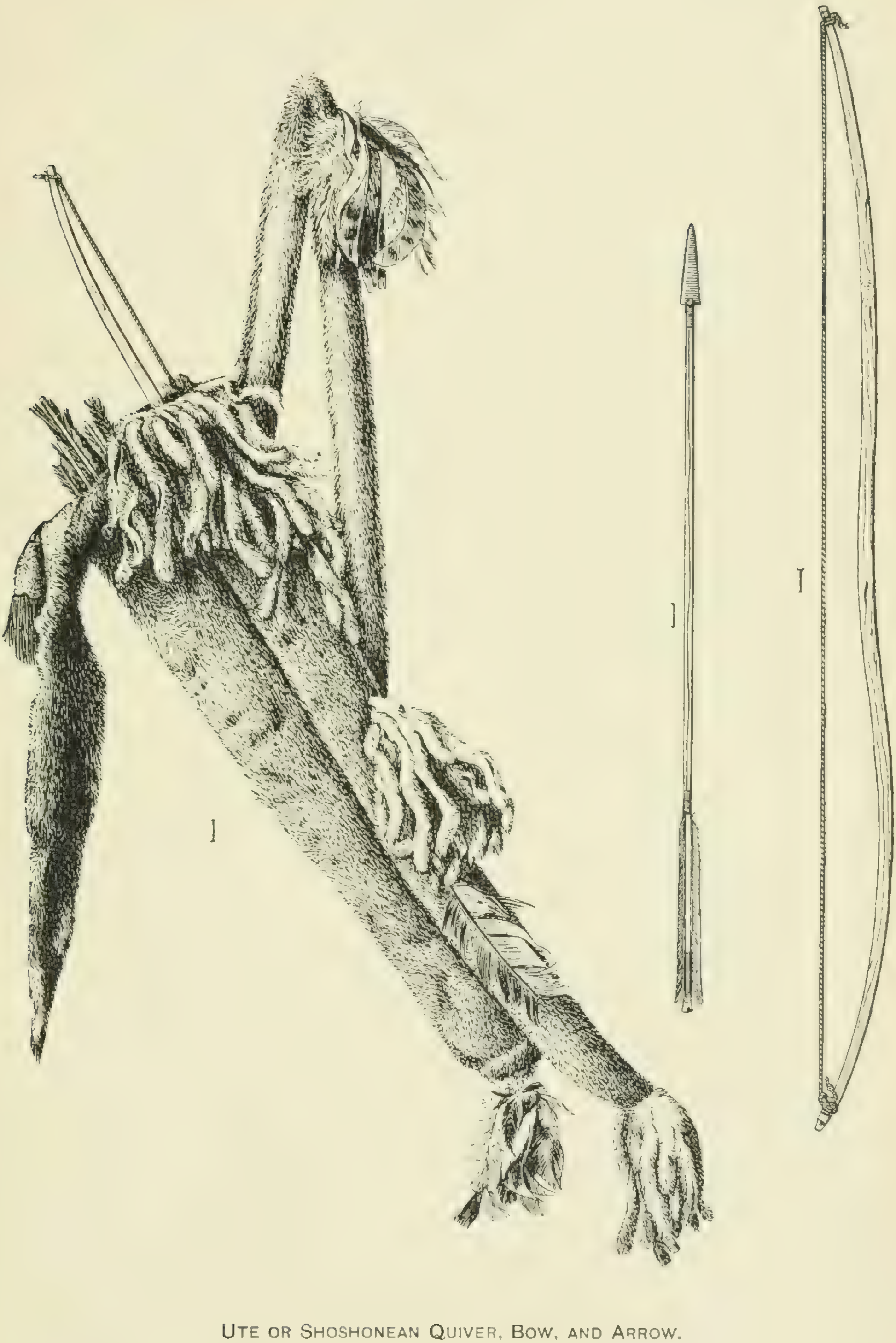
EXPLANATION OF PLATE LXXXIX.

UTE OR SHOSHONEAN QUIVER, BOW, AND ARROW.

QUIVER, deerskin; bow case, arrow case, and bandolier made of the same material, with the fur side outward. Adorned with fringes of the same skin cut in strips and with tufts of split feathers in which the stiff mid-rib has been removed. Length: bow case, 34 inches; arrow case, 28 inches.

Cat. No. 19843, U. S. N. M. Ute Indians, Shoshonean stock, Utah. Collected by Maj. J. W. Powell.

NOTE.—There is no tool bag, but depending from the top of the arrow case is a brush made of porcupine skin with the bristles left on. The bow is not sinew-lined, the arrow is of the universal Shoshonean type, and resembles those of the eastern Rocky Mountain tribes.



UTE OR SHOSHONEAN QUIVER, BOW, AND ARROW.

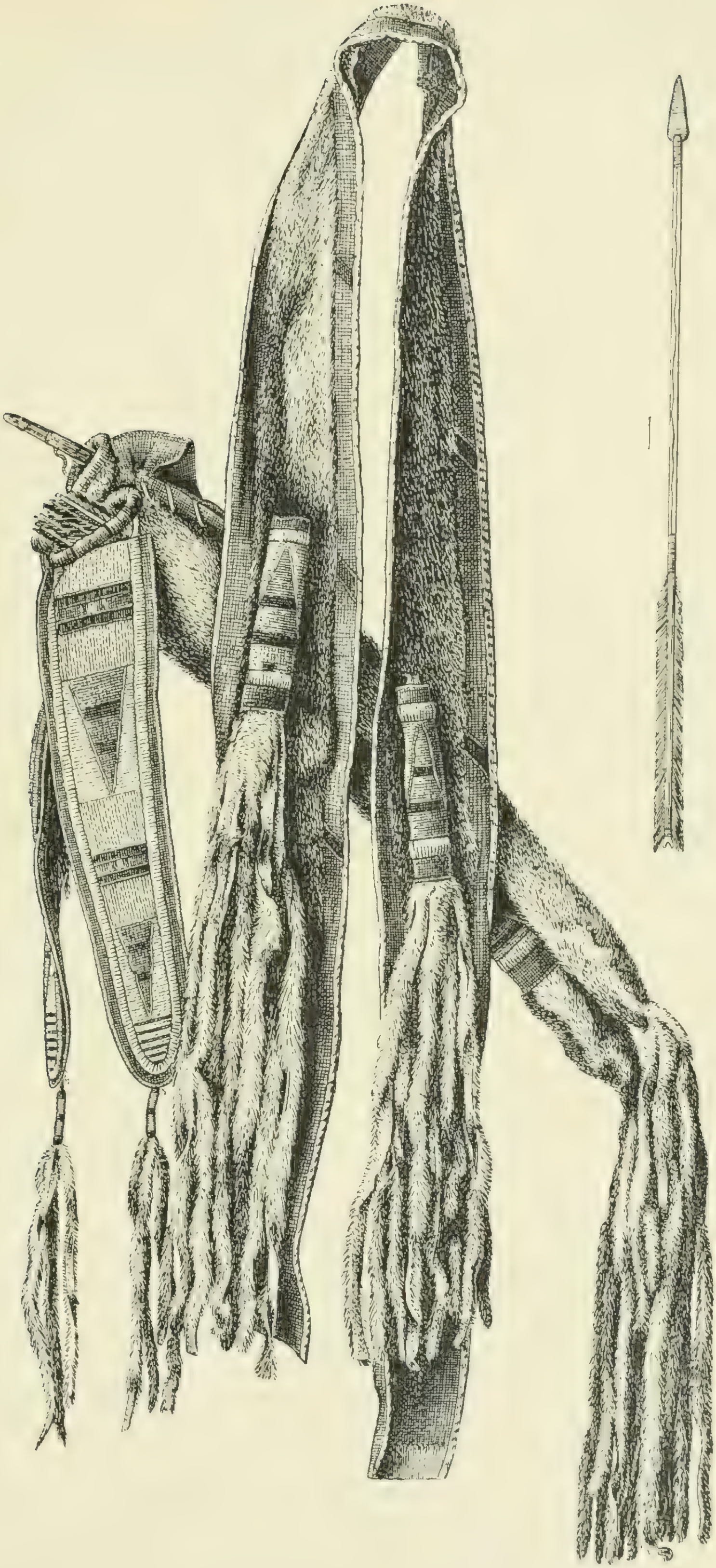
EXPLANATION OF PLATE XC.

NEZ PERCÉ OR SHAHAPTIAN QUIVER, BOW, AND ARROW, WITH SINUOUS SHAFT GROOVE.

FIG. 1. QUIVER, otter skin; bow case and arrow case separate. Each of these is a narrow bag with the fur side of the bag outward. The bottom of the bow case has a broad band of buckskin with red flannel borders. The surface of the buckskin is covered with red, blue, green, and white beads in beautiful patterns. The bandolier is also of otter skin with a broad border of red flannel. On either side of the bandolier, and from the lower end of the bow case and arrow case, are long fringes made of strips of otter skin. The fringe of the bandolier is also adorned with a band of beadwork similar to that on the bow case. The upper border of the bow case and the arrow case are also decorated with beadwork, and long flaps of rawhide entirely covered with beaded patterns. This is a very beautiful object. Length of bow case, 20 inches; arrow case, 30 inches. Length of bandolier, 8 feet.

Cat. No. 29886, U. S. N. M. Rocky Mountain Indians, tribe unknown. Collected by Dr. Fred. Kober.

NOTE.—A great many of the most beautiful objects in the National Museum were gathered by Army officers, who did not always know the exact tribe from which specimens were obtained. Quivers of this type are made by the Algonquian Siouan, Shoshonean, Salishan, and Shahaptian tribes of Montana.



NEZ PERCÉ OR SHALAPTIAN QUIVER, BOW, AND ARROW WITH SINUOUS SHAFT GROOVES.

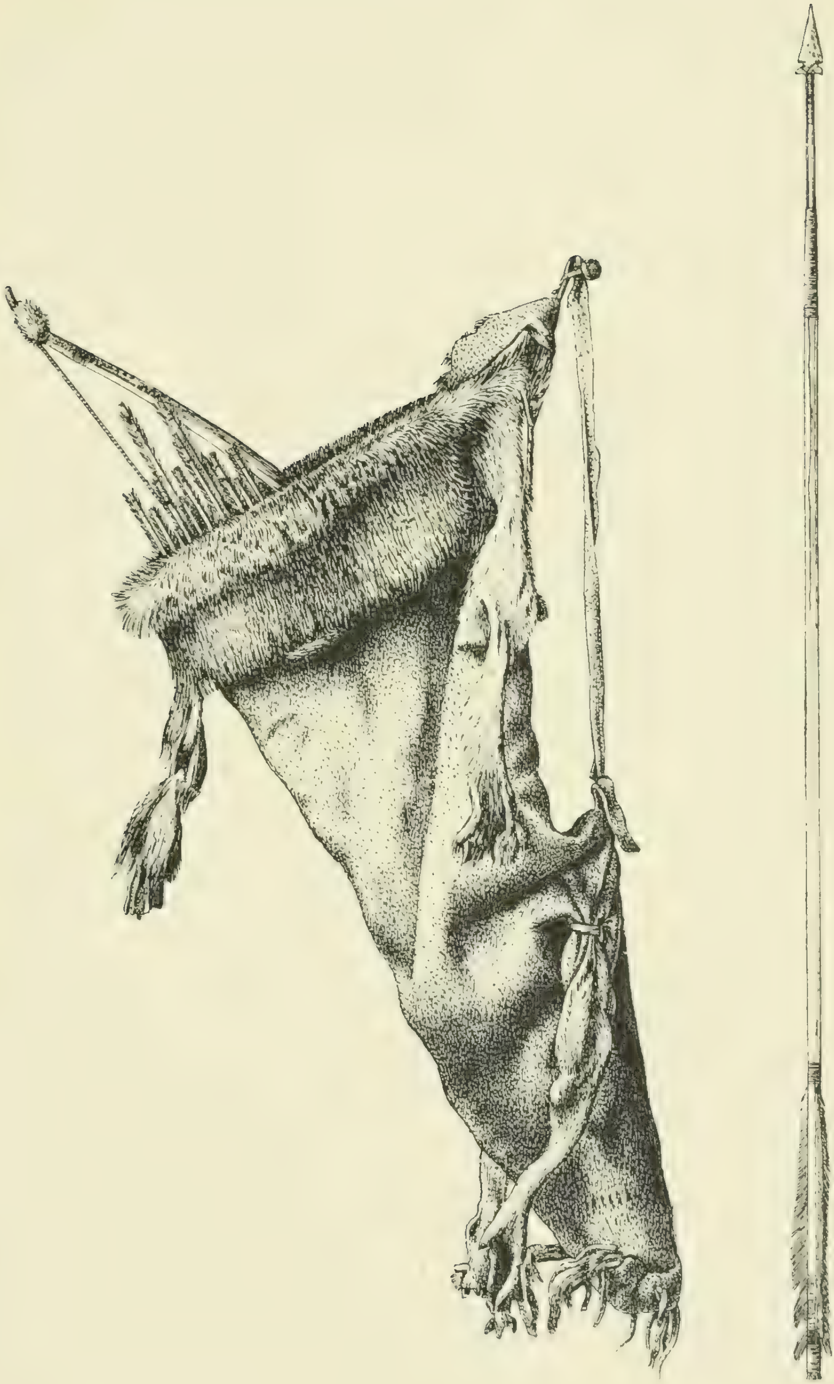
EXPLANATION OF PLATE XCI.

McCloud River (Cal.) Quiver, Sinew-lined Bow, and Foreshafted Arrow.

Fig. 1. Quiver, made of a whole deerskin with hair side inward. The skin of the legs has been left on and serve as pendants. The mouth is sewed up with buckskin strings and the ears protrude from the outside. There is no distinction between the bow case and arrow case. The whole forms a hide sack in which the bows and arrows are kept together. The bandolier is a mere strip of buckskin attached to the upper border and the middle of the quiver. Length: 40 inches.

Cat. No. 19322, U. S. N. M. McCloud River Indians, Copehan stock, Central California. Collected by Livingston Stone.

From this point southward the compound quiver disappears.



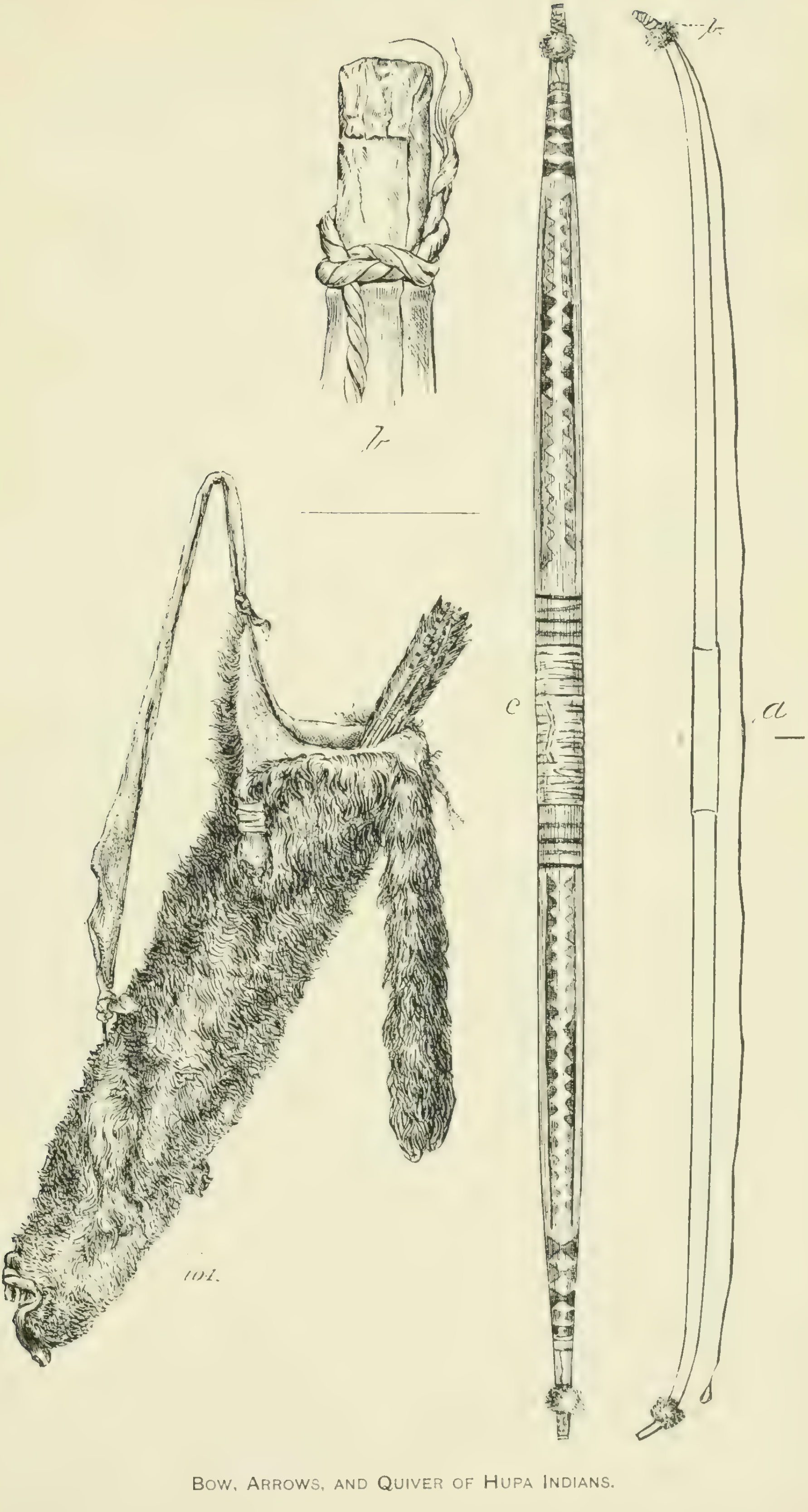
McCLOUD RIVER (CAL.) QUIVER, SINEW-LINED BOW, AND FORESHAFTED ARROW.

EXPLANATION OF PLATE XCII

BOW, ARROWS, AND QUIVER OF THE HUPA INDIANS, OF CALIFORNIA.

Bow made of yew, broad and thin in the middle and tapering toward the ends, which are turned back. The nocks are wrapped with buckskin and trimmed with strips of otter skin. The back of the bow is lined with shredded sinew, laid on in glue and painted. The arrows have been described in the plate devoted to California types.

The quiver is made of the skin of the coyote, and is used as a bag for holding the bows and arrows. The method of finishing off the sinew at the end of the bow to constitute the nock and of fastening the bowstring is shown in the plate.



BOW, ARROWS, AND QUIVER OF HUPA INDIANS.

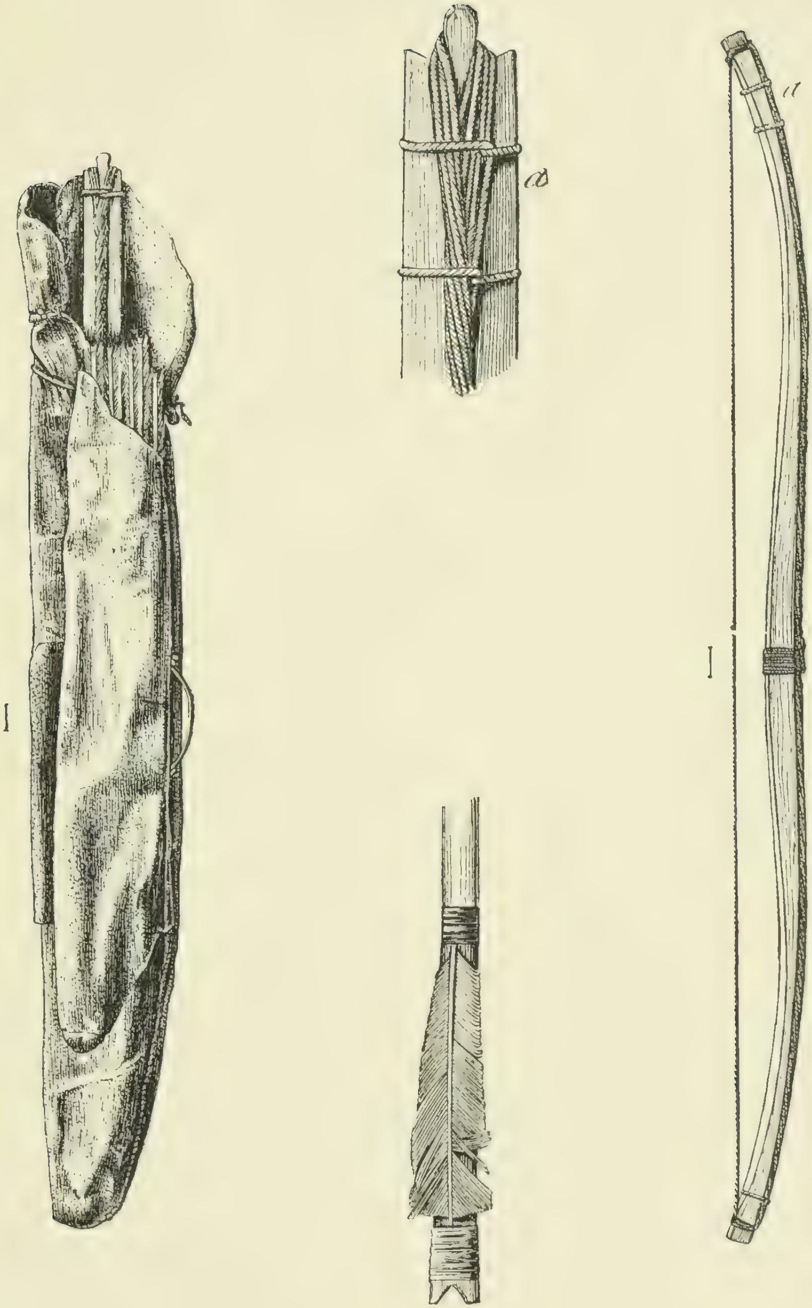
EXPLANATION OF PLATE XCIII.

CUMBERLAND GULF ESKIMO QUIVER, SINEW-BACKED BOW, AND TWO-FLAT-FEATHERED ARROW.

FIG. 1. QUIVER, made of seal skin deprived of hair. The bow case and arrow case are separate. Owing to exigencies of the sinew-backed bow the bow case is very large, while the arrow case is very short. To the stiffener on the back, by means of two thongs of rawhide, is attached a wire handle, probably taken from an old pail. The bow case has a hood for inclosing the bow. Length: bow case, 37 inches; arrow case, 25 inches.

Cat. No. 30015, U. S. N. M. Eskimo, Cumberland Gulf. Collected by W. A. Mintzer.

It will be remembered that Mr. Murdoch calls attention to the greater simplicity of the eastern Eskimo bows. Notice also the purely typical Eskimo flat feathers, one on each side of the flat nock, made for the Mediterranean release.



CUMBERLAND GULF ESKIMO QUIVER, SINEW-BACKED BOW, AND TWO-FLAT-FEATHERED ARROW.

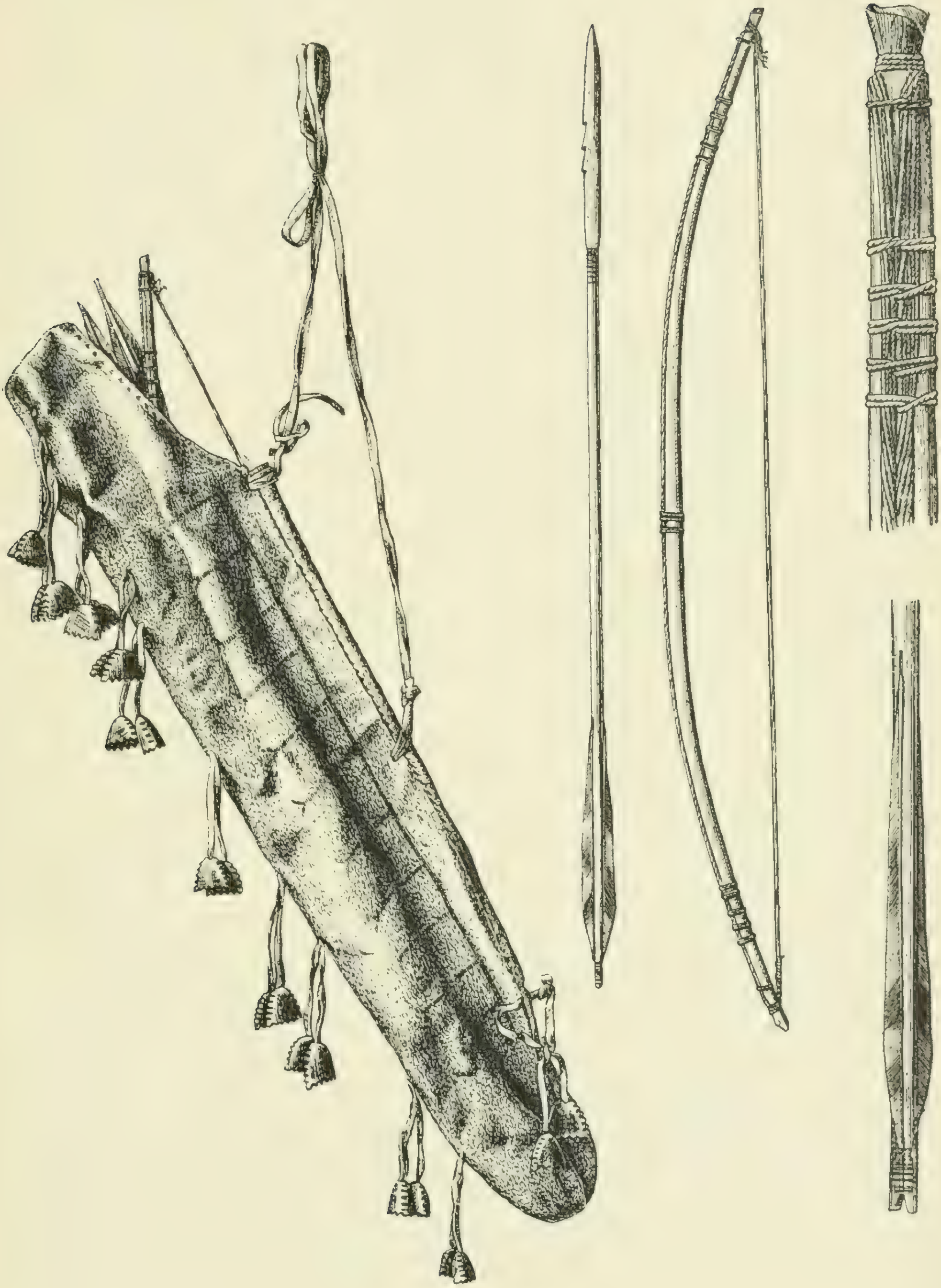
EXPLANATION OF PLATE XCIV.

FORT ANDERSON ESKIMO QUIVER, SINEW-BACKED BOW, AND TWO-FEATHER BARBED ARROW.

FIG. 1. QUIVER (model); bag of deerskin without the hair. Made in the shape of an ordinary arrow case with a hood. Along the short margin is a stiffener of wood. Along the outer or longer margin are decorations made by suspending the false hoofs of the deer to short thongs of buckskin. Bandolier, simple string of rawhide attached to the stiffener. Length, 20 inches.

Cat. No. 7481, U. S. N. M. Eskimo, Fort Anderson, Canada. Collected by Robt. McFarlane.

NOTE.—This model of a quiver contains also miniature sinew-backed bow and arrows, but they are all correctly made in imitation of originals. Among the Eskimo, quivers of this form are very common and are long enough to contain the arrows and the bow within the hood.



FORT ANDERSON ESKIMO QUIVER, SINEW-BACKED BOW, AND TWO-FEATHER BARBED ARROW.

ORIENTAL SCHOLARSHIP DURING THE PRESENT CENTURY.*

By Prof. FREDERICK MAX MÜLLER.

- - - When we wish to express something removed from us as far as it can be, we use the expression "So far as the East is from the West." Now what we who are assembled here are aiming at, what may be called our real *raison d'être*, is to bring the East, which seems so far from us, so distant from us, nay, often so strange and indifferent to many of us, as near as possible—near to our thoughts, near to our hearts. It seems strange indeed that there should ever have been a frontier line to seperate the East from the West, nor is it easy to see at what time that line was first drawn, or whether there were any physical conditions which necessitated such a line of demarcation. The sun moves in unbroken continuity from East to West, there is no break in his triumphant progress. Why should there ever have been a break in the triumphant progress of the human race from East to West, and how could that break have been brought about? It is quite true that as long as we know anything that deserves the name of history, that break exists. The Mediterranean with the Black Sea, the Caspian with the Ural Mountains may be looked upon as the physical boundary that separates the East from the West. The whole history of the West seems so strongly determined by the Mediterranean, that Ewald was inclined to include all Aryan nations under the name of *Mediterranean*. But the Mediterranean ought to have formed not only the barrier, but likewise the connecting-link between Asia and Europe. Without that high-road leading to all the emporia of the world, without the pure and refreshing breezes, without the infinite laughter of the Mediterranean, there would never have been an Athens, a Rome; there would never have been that spirited and never-resting Europe, so different from the solid and slowly-changing Asiatic continent. Northern Africa, however, Egypt, Palestine, Phenicia, and Arabia, though in close proximity to the Mediterranean, belong in their history to the East, quite as much as

* Extracts from inaugural address by the president of the International Congress of Orientalists, London, 1892. (*Transactions of the Congress*, vol. I.)

Babylon, Assyria, Media, Persia, and India. Even Asia Minor formed only a temporary bridge between East and West, which was drawn up again when it had served its purpose. We ourselves have grown up so entirely in the atmosphere of Greek thought that we hardly feel surprised when we see nations such as the Phenicians and Persians, looked upon by the Greeks as strangers and barbarians, though in ancient times the former were far more advanced in civilization than the Greeks, and though the latter spoke a language closely allied to the language of Homer, and possessed a religion far more pure and elevated than that of the Homeric Greeks. The Romans were the heirs of the Greeks, and the whole of Europe succeeded afterwards to the intellectual inheritance of Rome and Greece. Nor can we disguise the fact that we ourselves have inherited from them something of that feeling of strangeness between the West and the East, between the white and the dark man, between the Aryan and the Semite, which ought never to have arisen, and which is a disgrace to everybody who harbors it. No one in these Darwinian days would venture to doubt the homogeneousness of the human species, the brotherhood of the whole human race; but there remains the fact that, as in ancient so in modern times, members of that one human species, brothers of that one human family, look upon each other, not as brothers, but as strangers, if not as enemies, divided not only by language and religion, but also by what people call blood, whatever they may mean by that term.

I wish to point out that it constitutes one of the greatest achievements of Oriental scholarship to have proved by irrefragable evidence that the complete break between East and West did not exist from the beginning; that in prehistoric times language formed really a bond of union between the ancestors of many of the Eastern and Western nations, while more recent discoveries have proved that in historic times also, language, which seemed to separate the great nations of antiquity, never separated the most important among them so completely as to make all intellectual commerce and exchange between them impossible. These two discoveries seem to me to form the highest glory of Oriental scholarship during the present century. - - -

I begin with the prehistoric world which has actually been brought to light for the first time by Oriental scholarship.

I confess I do not like the expression *prehistoric.* It is a vague term, and almost withdraws itself from definition. If real history begins only with the events of which we possess contemporaneous witnesses, then, no doubt, the whole period of which we are now speaking, and many later periods also would have to be called prehistoric. But if history means, as it did originally, research and knowledge of real events based on such research, then the events of which we are going to speak are as real and as truly historical as the battle of Waterloo. It is often supposed that students of Oriental languages and of the Science of Language deal with words only. We have learned by this time that there

is no such thing as "words only," that every new word represented really a most momentous event in the development of our race. What people call "mere words" are in truth the monuments of the fiercest intellectual battles, triumphal arches of the grandest victories won by the intellect of man. When man had formed names for body and soul, for father and mother, and not till then did the first act of human history begin. Not till there were names for right and wrong, for God and man, could there be anything worthy of the name of human society. Every new word was a discovery, and these early discoveries, if but properly understood, are more important to us than the greatest conquests of the kings of Egypt and Babylon.

Not one of our greatest explorers has unearthed with his spade or pick-axe more splendid palaces and temples, whether in Egypt or in Babylon, than the etymologist. Every word is the palace of a human thought; and in scientific etymology we possess the charm with which to call these ancient thoughts back to life. It is the study of words, it is the Science of Language, that has withdrawn the curtain which formerly concealed these ancient times and their intellectual struggles from the sight of historians. Even now, when scholars speak of languages, and families of languages, they often forget that languages mean speakers of languages, and families of speech pre-suppose real families, or classes, or powerful confederacies, which have struggled for their existence and held their ground against all enemies. Languages, as we read in the book of Daniel, are the same as nations that dwell on all the earth. If, therefore, Greeks and Romans, Celts, Germans, Slavs, Persians, and Indians, speaking different languages, and each forming a separate nationality, constitute, as long as we know them, a real historical fact, there is another fact equally real and historical, though we may refer it to a prehistoric period, namely, that there was a time when the ancestors of all these nations and languages formed one compact body, speaking one and the same language, a language so real, so truly historical, that without it there would never have been a real Greek, a real Latin language; never a Greek republic, never a Roman empire; there would have been no Sanskrit, no Vedas, no Avesta, no Plato, no Greek New Testament. We know with the same certainty that other nations and languages, also, which in historical times stand before us so isolated as Phenician, Hebrew, Babylonian, and Arabic, pre-suppose a pre-historic, that is, an antecedent powerful Semitic confederacy, held together by the bonds of a common language, possibly by the same laws, and by a belief in the same gods. Unless the ancestors of these nations and languages had once lived and worked together there would have been no common arsenal from which the leading nations of Semitic history could have taken their armor and their swords, the armor and swords which they wielded in their intellectual struggles, and many of which we are still wielding ourselves in our wars of liberation from error and in our conquests of

truth. These are stern, immovable facts, just as Mont Blanc is a stern, irremovable fact, though from a distance we must often be satisfied with seeing its gigantic outline only, not all its glaciers and all its crevasses. What I mean is that we must not attempt to discover too much of what happened thousands of years ago, or strain our sight to see what, from this distance in time, we can not see. - - -

Nothing has shaken the belief, for I do not call it more, that the oldest home of the Âryas was in the East. All theories in favor of other localities, of which we have heard so much of late, whether in favor of Scandinavia, Russia, or Germany, rest on evidence far more precarious than that which was collected by the founders of Comparative Philology. Only we must remember, what is so often forgotten, that when we say Âryas we predicate nothing—we can predicate nothing—but language. We know, of course, that languages pre-suppose speakers, but when we say Âryas we say nothing about skulls, or hair, or eyes, or skin, as little as when we say Christians or Mohammedans, English or Americans. All that has been said and written about the golden hair, the blue eyes, and the noble profile of the Âryas, is pure invention, unless we are prepared to say that Socrates, the wisest of the Greeks, was not an Ârya, but a Mongolian. We ought, in fact, when we speak of Âryas, to shut our eyes most carefully against skulls, whether dolichocephalic, or brachycephalic, or mesocephalic, whether orthognathic, prognathic, or mesognathic. We are completely agnostic as to all that, and we gladly leave it to others to discover, if they can, whether the ancestors of the Âryan speakers rejoiced in a Neanderthal or any other kind of skull that has been discovered in Europe or Asia. Till people will learn this simple lesson, which has been inculcated for years by such high authorities as Horatio Hale, Powell, and Brinton, all discussions on the original home of the Âryas are so much waste of time and temper.

There is the same difference of opinion as to the original home of the Semites, but all Semitic scholars agree that it was "somewhere in Asia." The idea that the Semites proceeded from Armenia has hardly any defenders left, though it is founded on an ancient tradition preserved in Genesis. An eminent scholar, who at the last moment was prevented by domestic affliction from attending our Congress, Prof. Guidi,* holds that the Semites came probably from the Lower Euphrates. Other scholars, particularly Dr. Sprenger, placed the Semitic cradle in Arabia. Prof. Nöldeke takes much the same view with regard to the home of the Semites, which I take with regard to the home of the Âryas. We can not with certainty fix on any particular spot, but that it was "somewhere in Asia" no scholar would ever doubt.

It is well known also that some high authorities, Dr. Hommel, for instance, and Prof. Schmidt, hold that the ancestors of the Semites and Âryas must for a time have lived in close proximity, which would be a

* *Della sede primitiva dei Popoli, Semitici*, "Proceedings of the Accademia dei lincei," 1878–'79.

new confirmation of the Asiatic origin of the Âryas. But we hardly want that additional support. Benfey's arguments in favor of a European origin of the Âryas were, no doubt, very ingenious. But, as his objections have now been answered by one,* the old arguments for an Asiatic home seem to me to have considerably gained in strength. I, at all events, can no longer join in the jubilant chorus that, like all good things, our noble ancestors, the Âryas, came from Germany. Dr. Schrader, who is often quoted as a decided supporter of a European origin of the Âryas, is far too conscientious a scholar to say more than that all he has written on the subject should be considered "as purely tentative." (Preface, p. vi.)

With regard to time, our difficulties are greater still, and to attempt to solve difficulties which can not be solved, seems to me no better than the old attempt to square the circle. If people are satisfied with approximate estimates, such as we are accustomed to in geology, they may say that some of the Âryan languages, such as Sanskrit in India, Zend in Media, must have been finished and used metrical form about 2000 B. C. Greek followed soon after. And when it is said that these languages were finished 2000 B. C., that means simply that they had become independent varieties of that typical Âryan language which had itself reached a highly finished state long before it was broken up into these dialects. This typical language has been called the *Proto-Âryan* language. We are often asked why it should be impossible to calculate how many centuries it must have taken before that Proto-Âryan language could have become so differentiated and so widely divergent as Sanskrit is from Greek, or Latin from Gothic. If argued geologically, we might say, no doubt, that it took a thousand years to produce so small a divergence as that between Italian and French, and that therefore many thousands of years would not suffice to account for such a divergence as that between Sanskrit and Greek. We might, therefore, boldly place the first divergence of the Âryan languages at 5000 B. C., and refer the united Âryan period to the time before 5000 B. C. That period again would require many thousands of years, if we are to account for all that had already become dead and purely formal in the Proto-Âryan language before it began to break up into its six ethnic varieties, that is, into *Celtic*, *Teutonic*, *Slavonic*, *Greek*, *Latin*, and *Indo-Eranic*. - - -

If then we *must* follow the example of geology and fix chronological limits for the growth of the Proto-Aryan language previous to the consolidation of the six national languages 10,000 B. C. would by no means be too distant as to the probable limit of what I should call our historical knowledge of the existence of Aryan speakers somewhere in Asia.

And what applies to those Aryan speakers applies with even greater force to the Semitic, because the earliest monuments of Semitic speech,

* "Three lectures on the science of language," pp. 60 *et seq.*

differentiated as Babylonian, Phenician, Hebrew, and Arabic, go back, as we are told, far beyond the earliest documents of Sanskrit or Greek. Here also we must admit a long period previous to the formation of the great national languages, because thus only can the fact be accounted for that on many points, so modern a language as Arabic is more primitive than Hebrew, while, in other grammatical formations Hebrew is more primitive than Arabic.*

Whether it is possible that these two linguistic consolidations, the Aryan and Semitic, came originally from a common source is a question which scholars do not like to ask, because they know that it does not admit of a scholar-like answer. No scholar would deny the possibility of an original community between the two during their radical period, and previous to the development of any grammatical forms. But the handling of this kind of linguistic protoplasm is not congenial to the student of language, and must be left to other hands. Still, such an attempt should not be discouraged altogether, and if they are carried out in the same spirit in which in the last number of the "*Journal of the German Oriental Society*," Prof. Erman has tried to prove a close relationship between Semitic and Egyptian, they deserve the highest credit. Another question also which carries us back still further into unknown antiquity—whether it is possible to account for the origin of languages, or rather of human speech in general—is one which scholars eschew, because it is one to be handled by philosophers rather than by students of language. I must confess, the deeper we delve, the farther the solution of this problem seems to recede from our grasp; and we may here too learn the old lesson that our mind was not made to grasp beginnings. We know the beginnings of nothing in this world, and the problem of the origin of language, which is but another name for the origin of thought, evades our comprehension quite as much as the problem of the origin of our planet and of the life upon it, or the origin of space and time, whether without or within us. History can dig very deep, but, like the shafts of our mines, it is always arrested before it has reached the very lowest stratum. Students of language, and particularly students of Oriental languages, have solved the problem of the origin of species in language, and they had done so long before the days of Darwin; but like Darwin, they have to accept certain original germs as given, and they do not venture to pierce into the deepest mysteries of actual creation or cosmic beginnings.

And yet, though accepting this limitation of their labors as the common fate of all human knowledge, Oriental scholars have not altogether labored in vain. No history of the world can in future be written without its introductory chapter on the great consolidations of the ancient Aryan and Semitic speakers. That chapter may be called prehistoric, but the facts with which it deals are thoroughly historical, and I say once more, in the eyes of the student of language, they are

* See Driver, *Hebrew Tenses*, p. 132.

as real as the battle of Waterloo. They form the solid foundation of all later history. They determine the course of the principal nations of ancient history as the mountains determine the course of rivers. Try only to realize what is meant by the fact that there was a time and there was a place where the ancestors of the poets of the Veda and of the prophets of the Zend Avesta shook hands and conversed freely with the ancestors of Homer, nay, with our own linguistic ancestors, and you will see what a shifting of scenery, what a real transformation scene Oriental students have produced on the historical stage of the world. They have brought together the most valuable and yet the least expensive museum of antiquities, namely, the words which date from the time of an undivided Aryan and an undivided Semitic brotherhood; relics older than all Babylonian tablets or Egyptian papyri: relics of their common thoughts, their common religion, their common mythology, their common folk-lore, nay, as has lately been shown by Leist, Kohler, and others, relics of their common jurisprudence also. - - -

At the present moment, when the whole world is preparing for the celebration of the discovery of America, or what is called the New World, let us not forget that the discoverers of that old, that prehistoric world of which I have been speaking, deserve our gratitude as much as Columbus and his companions. The discoveries of Sir William Jones, Schlegel, Humboldt, and of my own masters and fellow-workers, Bopp, Pott, Burnouf, Benfey, Kuhn, and Curtius, will forever remain a landmark in the studies devoted to the history, that is, the knowledge of our race, and, in the end, the knowledge of ourselves. If others have followed in their footsteps and have proved that these bold discoverers have sometimes been on a wrong track let them have full credit for what they have added, for what they have corrected, and what they have rejected; but a Moses who fights his way through the wilderness, though he dies before he enters on the full possession of the promised land, is greater than all the Joshuas that cross the Jordan and divide the land. Many travellers now find their way easily to Africa and back; but the first who toiled alone to discover the sources of the Nile, men such as Burton, Speke, and Livingstone, required often greater faith and greater pluck than those who actually discovered them. As long as I live I shall protest against all attempts to belittle the true founders of the Science of Language. Their very mistakes often display more genius than the corrections of their Epigoni.

It may be said that this great discovery of a whole act in the drama of the world, the very existence of which was unknown to our forefathers, was due to the study of the Science of Language rather than to Oriental scholarship. But where would the Science of Language have been without the students of Sanskrit and Zend, of Hebrew and Arabic? At a Congress of Orientalists we have a right to claim what is due to

them, and I doubt whether anybody here present would deny that it is due in the first place to Oriental scholars, such as Sir W. Jones, Colebrooke, Schlegel, Bopp, Burnouf, Lassen, and Kuhn, if we now have a whole period added to the history of the world, if we now can prove that long before we knew anything of Homeric Greece, of Vedic India, of Persia, Greece, Italy, and all the rest of Europe, there was a real historical community formed by the speakers of Aryan tongues, that they were closely held together by the bonds of a common speech and common thoughts. It is equally due to the industry and genius of Oriental scholars, such as De Sacy, Gesenius, Ewald, and my friend the late Prof. Wright, if it can no longer be doubted that the ancestors of the speakers of Babylonian and Assyrian, Syriac, Hebrew, Phenician, and Arabic formed once one consolidated brotherhood of Semitic speech, and that however different they are when they appear for the first time in their national costumes on the stage of history they could once understand their common words and common thoughts like members of one and the same family. Surely this is an achievement on which Oriental scholarship has a right to take pride, when it is challenged to produce its title to the gratitude of the world at large.

If we now turn our attention to another field of Oriental scholarship which has been fruitful of results of the greatest importance to the student of history, and to the world at large, we shall be able to show, not indeed that Oriental scholars have created a whole period of history, as in the case of the Âryas and Semites, before their respective separation, but that they have inspired the oldest period in the history of the world with a new life and meaning. Instead of learning by heart the unmeaning names of kings and the dates of their battles, whether in Egypt, or Babylon, in Syria and Palestine, we have been enabled, chiefly through the marvellous discoveries of Oriental scholars, to watch their most secret thoughts, to comprehend their motives, to listen to their prayers, to read even their private and confidential letters. Think only what ancient Egypt was to us a hundred years ago! A Sphinx buried in a desert, with hardly any human features left. And now, not only do we read the hieroglyphic, the hieratic, and demotic inscriptions, not only do we know the right names of kings and queens 4000 or 5000 years B. C., but we know their gods, their worship; we know their laws and their poetry; we know their folk-lore and even their novels. Their prayers are full of those touches which make the whole world feel akin. Here is the true Isis, here is Human Nature, unveiled. The prayers of Babylon are more formal; still, how much more living is the picture they give us of the humanity of Babylon and Nineveh, than all the palaces, temples, and halls! And as to India, think what India was to the scholars of the last century! A name and not much more. And now! Not only have the ancient inhabitants ceased to be mere idolaters or niggers; they have been recognized as our brothers in language and thought.

The Veda has revealed to us the earliest phases in the history of natural religion, and has placed in our hands the only safe key to the secrets of Âryan mythology. Nay, I do not hesitate to say that there are rays of light in the Upanishads and in the ancient philosophy of the Vedânta which will throw new light, even to-day, on some of the problems nearest to our own hearts. And not only has each one of the ancient Oriental Kingdoms been reanimated and made to speak to us, like the gray, crumbling statue of Memnon, when touched by the rays of dawn, but we have also gained a new insight into the mutual relations of the principal nations of antiquity. Formerly, when we had to read the history of the world, every one of the great Kingdoms of the East seemed to stand by itself, isolated from all the rest, having its own past, unconnected with the past history of other countries.

China, for instance, was a world by itself. It had always been inhabited by a peculiar people, different in thought, in language, and in writing even from its nearest neighbors.

Egypt, in the gray morning of antiquity, seemed to stand alone, like a pyramid in a desert, self contained, proud, and without any interest in the outside world, entirely original in its language, its alphabet, its literature, its art, and its religion.

India, again, has always been a world by itself, either entirely unknown to the Northern nations, or surrounded in their eyes by a golden mist of fable and mystery.

The same applies more or less to the great Mesopotamian Kingdoms, to *Babylon* and *Nineveh*. They, too, have their own language, their own alphabet, their own religion, their own art. They seem to owe nothing to anybody else.

It is somewhat different with *Media* and *Persia*, but this is chiefly due to our knowing hardly anything of these countries before they appear in conflict with their neighbors, either as conquerors or as conquered, on the ancient battle-fields of history.

In fact, if we look at the old maps of the ancient world, we see them colored with different and strongly contrasting colors, which admit of no shading, of no transition from one to the other. Every country seemed a world by itself, and, so far as we can judge from the earliest traditions which have reached us, each nation claimed even its own independent creation, whether from their own gods, or from their own native soil. China knows nothing of what is going on in Babylon and Egypt; Egypt hardly knows the name of India; India looks upon all that is beyond the Himalayan snows as fabulous, while the Jews, more than all the rest, felt themselves a peculiar people, the chosen people of God.

Until lately, if it was asked whether there was any communication at all between the leading historical nations of the East, the answer was that no communication, no interchange of thought, no mutual influence was possible, because language placed a barrier between

them which made communication, and more particularly free intellectual intercourse, entirely impossible.

If therefore it seemed that some of these ancient nations shared certain ideas, beliefs, or customs in common, the answer always was that they could not have borrowed one from the other, because there was really no channel through which they could have communicated, or borrowed from each other by means of a rational and continuous converse. Thanks to the more recent researches of Oriental scholars, this is no longer so. One of the first and one of the strongest proofs that there was, in very ancient times, a very active intellectual intercourse between Âryan and Semitic nations, is the Greek Alphabet. The Greeks never made any secret of their having borrowed their letters from Phenician schoolmasters. They called their letters Phenician, as we call our numerical figures Arabic, while the Arabs called them Indian. The very name of *Alphabet* in Greek is the best proof that at the time when the Greeks were the pupils of Phenician writing-masters, the secondary names of the Semitic letters, Aleph, Beth, Gimel, Daleth, had already been accepted. Originally the Aleph was the picture not of a bull, but of an eagle: Beth not of a house, but of another bird; Gimel not of a camel, but of a vessel with a handle; Daleth of a stretched out hand. This intercourse between Phenicians and Greeks must have taken place previous to the beginning of any written literature in Greece, previous therefore to the seventh century at least. When we speak of Greeks and Phenicians in general, we must guard against thinking of whole nations, or of large numbers. The work of humanity in the past, more even than in the present, was carried on by the few, not by the many, by what Disraeli called "the men of light and leading," the so-called Path-makers of the ancient world. They represent unknown millions, standing behind them, as a Commander-in-chief represents a whole army that follows him. The important point is that in the alphabet we have before us a tangible document, attesting a real communication between these leaders of progress and civilization in the East and in the West, a bridge between Phenicia and Greece, between Semitic and Âryan people. The name of the letter *Alpha* in the Greek alphabet is a more irresistible proof of Phenician influence than all the legends about Kadmos and Thebes, about a Phenician Herakles or a Phenician Aphrodite. It is strange that not one of the classical scholars who have written on the traces of Phenician influence in the religion and mythology of Greece should have availed himself of the Greek alphabet as the most palpable proof of a real and most intimate intercourse between the Phenicians and the early inhabitants of Greece.

But their discoveries have opened even wider vistas. It was one of the most brilliant achievements, due to the genius of the Vicomte de Rougé to have shown that, though they discovered many things, the Phenicians did not discover the letters of the alphabet. Broken arches

of the same bridge that led from Phenicia to Greece have been laid bare, and they lead clearly from Phenicia back to Egypt. It is well known that even the ancients hardly ever doubted that the alphabet was originally discovered in Egypt and carried from thence by the Phenicians to Greece and Italy. Plato, Diodorus Siculus, Plutarch, and Gellius, all speak of Egypt as the cradle of the alphabet, and Tacitus (*Annals*, XI. 14), who seems to have taken a special interest in this subject, is most explicit on that point. It was supposed for a time that the Egyptians simply took certain hieroglyphic signs, and made them stand for their initial letters. This was called the akrological theory, but it is no longer tenable. The alphabet was never a discovery, in the usual sense of the word; it was like all the greatest discoveries, a natural growth. It arose, without any intentional effort, from the employment of what are called complimentary hieroglyphics.* - - -

What the Vicomte de Rougé did, was to select the most ancient forms of the Phenician alphabet, as they are found on the sarcophagus of Eshmunezar (or better still, on the Stone of Mesha, which was not known in his time), and to show how near they came, not indeed to the most ancient hieroglyphics, but to certain hieratic cursive signs which have the same phonetic values as their corresponding Phenician letters. This was a most brilliant discovery, and I still possess a very scarce paper which he sent me in 1859. He never published a full account of his discovery himself, but after his death his notes were published by his son in 1874.

I know quite well that some scholars have remained skeptical as to the Egyptian origin of the Phenician letters. My friend Lepsius was never quite convinced. Attempts have been made to derive the Phenician letters from a cuneiform source or from the Cypriote letters, but the result has hitherto been far from satisfactory. The Phenician letters must have had ideographic antecedents. Where are we to look for them, if not in Egypt? What has always made me feel convinced that Rougé was right is the fact that we have to deal with a series, and that 15 out of the 23 letters of this series are almost identical in Phenician and in Egyptian. We are perfectly justified, therefore, in making a certain allowance for some modifications in the rest. These modifications are certainly not greater than the modifications which the Phenician letters underwent later in their travels over the whole civilized world. But there is another argument in Rougé's favor which has often been ignored, namely, the fact that the Egyptians, whenever they had to transcribe foreign words, have fixed in many cases on the identical letters which served as the prototypes of the Phenician alphabet. This fact, first pointed out by Dr. Hincks, is one of the many valuable services which that ingenious scholar has rendered to hieroglyphic studies; and the Vicomte de Rougé has been the first to acknowledge how much his own discovery owes to the labors of Dr.

* Hincks, *Egyptian Alphabet*, p. 7.

Hincks, particularly to his paper on the Egyptian alphabet published in "*The Transactions of the Irish Academy* in 1847." All the facts concerning the history of the alphabet have been carefully put together in Lenormant's great work, "*Essai sur la Propagation de l'Alphabet Phénicien.*" Here, then, we have a clear line of communication between Egypt, Phenicia, and Greece, which Oriental scholarship has laid bare before our eyes. To judge from the character of the hieratic letters as copied by the Phenicians, the copying must have taken place about the nineteenth century B. C.*; according to others, even at an earlier date. It is well known that hieroglyphic writing for monumental purposes goes back in Egypt to the Fourth, or even the Second Dynasty†, and on these earliest inscriptions we not only find the hieroglyphic system of writing fully developed, but we actually see hieroglyphic pictures of paper‡ and books, of inkstands and pens. But here again the beginnings escape us, and the origin of writing, though we know the conditions under which it took place withdraws itself from our sight almost as much as the origin of language itself. The question has been asked whether, as the oldest cuneiform writing clearly betrays an ideographic origin, its first germs could be traced back to the ideographic alphabet of Egypt. This would make Egypt the schoolmaster, or at least the older schoolfellow of the Mesopotamian Kingdoms. But, whatever the future may disclose, at present Oriental scholarship has no evidence with which to confirm such a hypothesis.

The same applies to another hypothesis which has been advocated with great ingenuity by one of the members of our Congress, M. Terrien de Lacouperie. He thinks it possible to show that the oldest Chinese letters, which, as is generally admitted, had an ideographic beginning like that of the Egyptian hieroglyphics, owed their first origin to Babylon. It is generally supposed that the cuneiform alphabet used by the Semitic inhabitants of Babylonia and Assyria was invented by a non-Semitic race called Sumerians and Accadians. Whether the Chinese borrowed from these races or from the Babylonians is difficult to decide. It must likewise remain for the present an open question whether these Sumerians and Accadians can be identified with a race dwelling originally in the North and East of Asia. There are scholars who place the original home of the Accadians on the Persian Gulf, though the evidence for this view also is very weak. We must not forget that ideographs, such as pictures of the sun and moon or of the superincumbent sky, of mountains and plants, of the mouth and nose, of eyes and ears, must of necessity share certain features in common in whatever country they are used for hieroglyphic purposes. The scholar has the same feeling with regard to these very general ideographic pictures which he has with regard to the very indefinite roots of

*J. de Rougé *Memoire sur l'Origine Egyptienne de l'Alphabet Phénicien*, 1874, p. 108.
†In the Ashmolean Museum at Oxford is a monument of the Second Dynasty.
‡Rougé, *l. c.*, p. 103.

language which are supposed to be shared in common by the Semitic and Aryan families of speech. Both are too protoplastic, too jelly-like, too indefinite for scientific handling.*

Still no researches, if only carried on methodically, should be discouraged *a priori*, and we must always be willing to learn new lessons however much they may shock our inherited opinions.

It is not so very long ago that the best Semitic scholars stood aghast at the idea that the cuneiform letters were borrowed from a non Semitic race, and that some of the cuneiform inscriptions should contain specimens of a non-Semitic or Accadian language. We have got over this surprise, and though there are still some formidable skeptics, the fact seems now generally recognized that there was in very ancient times an intercourse between the Semitic and non-Semitic races of Asia as there was between the Egyptians and the Phenicians, and between the Phenicians and Greeks, that is, between the greatest people of antiquity, and that these non-Semitic people or Accadians were really the schoolmasters of the founders of the great Mesopotamian kingdoms. But though we must for the present consider any connection between Chinese and Babylonian writing as extremely doubtful, there can be no doubt as to the rapid advance of the cuneiform system of writing itself from East to West. This wonderful invention, more mysterious even than the hieroglyphic alphabet, soon overflowed the frontiers of the Mesopotamian kingdoms, and found its way into Persia and Armenia, where it was used, though for the purpose of inscriptions only, by people speaking both Aryan and non-Aryan languages. Here, then, we see an ancient intercourse between people who were formerly considered by all historians as entirely separate, and we are chiefly indebted to English scholars, such as Rawlinson, Norris, Sayce, Pinches, and others, for having brought to light some of the ruins of that long buried bridge on which the thoughts of the distant East may have wandered toward the West.

Few generations have witnessed so many discoveries in Oriental scholarship, and have lived through so many surprises, as our own. If any two countries seemed to have been totally separated in ancient times by the barriers both of language and writing they were Egypt with its hieroglyphic and Babylon with its arrow-headed literature. We only knew of one communication between Egypt and its powerful neighbors and enemies, carried on through the inarticulate and murderous language of war, of spears and arrows, but not of arrow-headed writings. Who could have supposed that the rows of wedges covering the cylinders of Babylonian libraries, which have taxed the ingenuity of our cleverest decipherers, were read without any apparent difficulty by scribes and scholars in Egypt about 1500 B. C.? Yet we possess

*Professor Hommel, in his paper submitted to our Congress, has pointed out striking similarities between Egyptian hieroglyphics and corresponding Babylonian ideographs. Who was the inventor and who the borrower, *adhuc sub judice lis est.*

now in the tablets found at Tel-el-Amarna, in Egypt, a kind of diplomatic correspondence, carried on at that early time, more than a thousand years before the invasion of Greece by Persia, between the kings of Egypt and their friends and vassals in Babylon, Syria, and Palestine. These letters were docketed in Egypt in hieratic writing, like the dispatches in our Foreign Office. They throw much light on the political relations then existing between the Kings of Egypt and the Kings of western Asia, their political and matrimonial alliances, and likewise on the trade carried on between different countries. They confirm statements known to us from hieroglyphic inscriptions in Egypt, more particularly those in the temple of Karnak. The spelling is chiefly syllabic, the language an Assyrian dialect. Doubtful Accadian words are often followed and explained by glosses in what may be called a Canaanite dialect, which comes very near to Hebrew. But how did the kings of Egypt understand these cuneiform dispatches? It is true we meet sometimes with the express statement that those to whom these missives were addressed had understood them,* as if this could not always be taken for granted. It is true also that these letters were mostly brought by messengers who might have helped in interpreting them, provided they had learned to speak and read Egyptian. But what is more extraordinary still, the King of Egypt himself, Amenophis III, when writing to a king whose daughter he wishes to marry, writes a dispatch in cuneiform letters, and in a language not his own, unless we suppose that the tablet which we possess was simply a translation sent to the King Kallimma Sin, and as such kept in the archives of the Egyptian Foreign Office.

It is curious to observe that the King of Egypt, though quite willing to marry the daughters of smaller potentates, is not at all disposed to send Egyptian princesses to them. For he writes in his own letters (p. 29) "A daughter of the King of the land of Egypt has never been given to a 'Nobody.'" Whatever else we may learn from these letters, they are not patterns of diplomatic language, if indeed the translation is in this case quite faithful.† In these dispatches, dating from 1400 B. C., a number of towns are mentioned, many of which have the same names as those known to us from hieroglyphic inscriptions. Some of these names have even survived to our own time, such as Misirîm for Egypt, Damascus, Megiddo, Tyre (Surrii), Sidon (Sidûna), Byblos (Guble), Beyrut (Birûta), Joppa (Yâpû), and others. Even the name of Jerusalem has been discovered by Sayce in these tablets, as *Uru'sal'im*, meaning in Assyrian the town of peace, a name which must have existed before the Jews took possession of Canaan. Some of these tablets (eighty-two) may be seen at the British Museum, others (160) at Berlin, most of the rest are in the museum at Gizeh. We are indebted to Mr. Budge

* See Tablets XXVI, LX, LXIX, LXXXIV.

† My skepticism on this point has been confirmed, for I see in an article by Prof. Sayce in the last number of the Academy that this translation is not quite correct.

for having secured these treasures for the British Museum, and to Dr. Bezold and Mr. Budge for having translated and published them.

To us this correspondence is of the greatest importance, as showing once more the existence of a literary and intellectual intercourse between western Asia and Egypt, of which historians had formerly no suspicion. If we can once point to such an open channel as that through which cuneiform tablets travelled from Babylonia and Syria to Egpyt, we shall be better prepared to understand the presence in Egypt of products of artistic workmanship also from western Asia, nay, from Cyprus, and even from Mycenæ. I possessed potsherds sent to me by Schliemann from Mycenæ, which might have been broken off from the same vessels of which fragments have been found at Ialysos, and lately in Egypt by Mr. Flinders Petrie. I have sent these potsherds to the British Museum to be placed by the side of the pottery from Ialysos, and to our University Museum at Oxford. Mr. Flinders Petrie in the *Academy*, June 25, 1892, writes: "Mykenæan vase-types are found in Egypt with scarabs, etc., of the Eighteenth Dynasty, and conversely objects of the Eighteenth Dynasty, including a royal scarab, are found at Mykenæ. And again, hundreds of pieces of pottery, purely Mykenæn in style, have been found in various dateable discoveries in Egypt, and without exception every datum for such, lies between 1500 and 1100 B. C. and earlier rather than later in that range." I do not mean to say that this fixes the date of the Mykenæan pottery, nor do I wish to rely on evidence which is contested by some of the best Egyptian scholars; otherwise, I should gladly have appealed to the names of the Mysians, Lycians, Carians, Ionians, and Dardanians, discovered in the epic of Pantaur about 1400 B. C., in the reign of Rameses II; and to the name of Achæans, read by certain Egyptian scholars in an inscription at Karnak, ascribed to the time of Meneptah, the son of Rameses II. What we shall have to learn more and more is that the people of antiquity, even though they spoke different languages and used different alphabets, knew far more of each other, even at the time of Amenophis III, or 1400 B. C., than was supposed by even the best historians. The ancient world was not so large and wide as it seemed, and the number of representative men was evidently very small. The influence of Babylon extended far and wide. We know that several of the strange gods worshiped by the Jews, such as Rimmon, Nebo, and Sin, came from Babylon. The authority of Egypt also was felt in Palestine, in Syria, and likewise in Babylon. The authenticity of the cuneiform dispatches found at Tel-el-Amarna in Egypt has lately received an unexpected confirmation from tablets found at Tel-el-Hesy, probably the ancient Lachish. Here a letter has been found addressed to Zimrida, who in the Tel-el-Amarna tablets was mentioned as governor of Lachish, where he was murdered by his people.* In the same place cylinders were found of Babylonian manufacture, between 2000 and

* *Academy*, July 9, 1892.

1500 B. C., and copies, evidently made of them in the West. Similar cylinders occur in the tombs of Cyprus and Syria, helping us to fix heir dates, and showing once more the intercourse between East and West, and the ancient migration of Eastern thought toward Europe.

Nor should we, when looking for channels of communication between the ancient kingdoms of Asia, forget the Jews, who were more or less at home in every part of the world. We must remember that they came originally from Ur of the Chaldees, then migrated to Canaan, and afterwards sojourned in Egypt, before they settled in Palestine. Afte that we know how they were led into captivity and lived in close proximity and daily intercourse with Medians, Persians, Babylonians, and Assyrians. They spoke of Cyrus, a believer in Ormazd, as the anointed and the shepherd of Jehovah, because he allowed them to return from Babylon to Jerusalem. Darius, likewise a follower of Zoroaster, was looked on by them as their patron, becaused he favored the re-building of the Temple at Jerusalem. When we consider these intimate relations between the Jews and their neighbors and conquerors, we can easily imagine what useful intermediaries they must always have been in the intellectual exchange of the ancient world.

There are two countries only which really remained absolutely isolated in the past, China and India. It is true that attempts have been made to show that the Chinese influenced the inhabitants of India in very ancient times by imparting to them their earliest astronomy. But Biot's arguments have hardly convinced anybody. And as to Chinese porcelain being found in ancient Egyptian tombs, this too has long been surrendered for lack of trustworthy evidence.

Nor have the attempts been more successful which were intended to show that the ancient astronomy of India was borrowed from Babylon. It is well known that the Babylonians excelled in astronomy, and that in latter times they became the teachers of the Greeks, and indirectly of the Indians. But the 27 Vedic Nakshatras or lunar stations are perfectly intelligible as produced on Indian soil, and require no foreign influences for their explanation. If the Indians had in Vedic times been the pupils of the Babylonians, other traces of that intercourse could hardly be absent. It was indeed thought for a time that one word at least of Babylonian origin had been discovered in the hymns of the Rig-Veda, the Babylonian *manâ*, a certain weight of gold. This word has certainly travelled far and wide. We find it in the tablets of Tel-el-Amarna, in Hebrew, in Arabic, in Greek, and in Latin,* *mina*, a mine. But the verse in the Rig-Veda in which this *manâ* was supposed to occur, requires a different interpretation nor would one word be sufficient to indicate a real intellectual intercourse between Babylonians and Vedic Indians. On the same ground we can hardly use the word *sindhu* in the Babylonian inscriptions as proving a commercial inter-

* Possibly in Egyptian, *Zeitschrift der D. Morgenl. Gesells.*; vol. XLVI, p. 111.

course between India and Babylon. *Sindhu*, as my learned friend, Prof. Sayce, informs me, occurs in cuneiform texts as far back as 3000 B. C. as the name of some textile fabric. In Sanskrit *saindhava* would mean what grows on the Sindhu or the Indus,* and would therefore be a very good name for cotton or linen. But so long as this word stands alone, it would not be safe to build any conclusions on it as to an ancient trade between India and Babylon.

For the present, therefore, we must continue to look upon China and India as perfectly isolated countries during the period of which we are here speaking. But though in the eyes of the historian the ancient literature of these two countries loses in consequence much of its interest, it acquires a new and peculiar interest of its own in the eyes of the philosopher. It is entirely home-grown and home-spun, and thus forms an independent parallel to all the other literature of the world. It has been truly said that the religion and the philosophy of India come upon us like meteors from a distant planet, perfectly independent in their origin and in their character. Hence, when they do agree with other religions and philosophies of the ancient world, they naturally inspire us with the same confidence as when two mathematicians, working quite independently, arrive in the end at the same results.†

It is true that in these days of unexpected discoveries we are never entirely safe from surprises. But as far as our evidence goes at present—and we can never say more—the idea once generally entertained and lately revived by Prof. Gruppe, that there was some connection between the ancient religion of India and those of Egypt and Babylon is, from a scholar's point of view, simply impossible. Before the time of Alexander the Great it would be very difficult to point out any foreign intellectual importation into the land of the Indus or the Seven Rivers. The knowledge of the alphabet may have reached India a little before Alexander's invasion. We know that Darius sent Skylax on a scientific expedition down to the mouth of the Indus. This expedition, like other scientific expeditions, was the forerunner of Persian conquests along the Indus. The people called in the cuneiform inscriptions *Gadâra* and *Hidhu*, that is, in Sanskrit, *Ganhdâra* and *Sindhu*, occur among the conquests of Darius, at least in his later inscriptions. It is quite possible therefore that even at that early time a knowledge of reading and writing may have been communicated to India. Travellers from India were seen by Ktesias in Persia at the beginning of the fifth century B. C., and he describes some whom he had seen himself as being as fair, or actually as white, as any in the world. Others he describes as black, not by exposure to the sun, but by nature. This was probably written at the same time when Buddha, in a sermon which he delivered (the Assalayana Sutta), said: "The

* M. M., *Physical Religion*, p. 87.

† Deussen, *Die Sûtras des Vedânte*, p. vi.

Brahmans are the white caste, the other castes are black." This refers to their color (*varna*), not, as has been supposed, to their character.

But we have as yet no real evidence of writing, not even of inscriptions, in India before the time of Asoka, in the third century B. C. The Indian alphabets certainly came from a Semitic alphabet, which was adapted, systematically, to the requirements of an Aryan language. We can see it still in a state of fermentation in the local varieties that have lately been pointed out by my friend, Prof. Bühler, the highest authority on this subject. As to the religion of Buddha being influenced by foreign thought, no true scholar now dreams of that. The religion of Buddha is the daughter of the old Brahmanic religion, and a daughter in many respects more beautiful than the mother. On the contrary, it was through Buddhism that India for the first time stepped forth from its isolated position, and became an actor in the historical drama of the world. A completely new idea in the history of the world was started at the third Buddhist Council in the third century B. C., under King Asoka, the idea of conquering other nations, not by force of arms, but by the power of truth. A resolution was proposed and carried at that council to send missionaries to all neighboring nations to preach the new gospel of Buddha. Such a resolution would never have entered into the minds of the ancient Egyptians, Babylonians, Assyrians, not even of the Brahmans. It pre-supposed quite a new conception of the world. It announced for the first time a belief that the different nations of the world, however separated from each other by language, religion, color, and customs, formed nevertheless one united family; that each of its members was responsible for the rest; in fact, that humanity was not an empty word.

It is a curious coincidence, if no more, that the name of the missionary who, according to the chronicle of Ceylon, was sent to the North, to the Himalayan border lands, namely *Madhyama*, should have been found in a Stûpa near Sanchi, as well as that of his fellow-worker, Kâsyapa. We read in an inscription: "These are (the relics) of the good man of the family of Kâsyapa, the teacher of the whole Haimavata," that is, the Himalayan border land.* We seldom find such monumental confirmations in Indian history. This important discovery, like so many others, was due to Gen. Cunningham, in one of his earlier works. (*The Bhilsa Topes*, pp. 119, 187, 317.)

China, the other isolated country of antiquity, was soon touched by the rising stream of Buddhism, and thus brought for the first time into contact with India and the rest of the world. The first waves of Buddhism seem to have reached the frontiers of China as early as the third century (217 B. C.), and so rapid and constant was its progress that in 61 B. C. Buddhism was accepted by the Emperor Mingti as one of the three state-religions of China. We soon hear of Buddhists in other countries also, and if we consider that we have now arrived

* Lassen, *Indische Alterthumskunde*, vol. II, p. 234, and p. xxxix.

at a third period in the history of antiquity, which may truly be called the Alexandrian or Alexandrinian period, we need not wonder that the military roads which have been opened from the Indus to the Euphrates and to the Mediterranean were soon trodden by peaceful travellers also, carrying both industrial and intellectual merchandise from East to West. From Kashmir, Buddhist missionaries seem to have penetrated into Hellenised Bactri. Alexander Polyhistor, who wrote between 80 and 60 B. C. attests their presence there under the name of *Samanioi*, which stands for the *Pâli* name *Samana*, a Buddhist friar. Their presence in Bactria is attested somewhat later, at the beginning of the third century A. D., by Clement of Alexandria, who speaks of the Samanaioi as powerful philosophers among the Bactrians, and again by Eusebius, at the beginning of the fourth century, who writes that among the Indians and Bactrians there are many thousands of Brâhmans. With regard to Bactria this can refer to Buddhists only, for the old orthodox Brahmans did not leave their country, and Brahman has always been retained by the Buddhists as a title of honour for themselves. Early traces of the Buddhist religion have been discovered likewise in the countries north of Bactria, in Tukhâra, and in the towns of Khoten, Yarkand, and Kashyar. M. Darmesteter has shown that in the second century B. C. Buddhist missionaries were hard at work in the western part of Persia, and it is a significant fact that the name of *Gautama*, the founder of Buddhism, occurs in the Avesta, in the Fravardin Yasht.* This shows how closely the most distant parts of the world had been brought together by the genius of Alexander the Great, and by the genius of that still greater conqueror, Gautama Sâkyamuni. Here again, it is mainly due to the labors of Oriental scholars that so many traces of the work done by Alexander and his successors have been rediscovered. With Alexander we have entered on a new period in the history of the world, a period marked by the first strong reaction of the West against the East, inaugurated in the fifth century B. C. by the victories of Marathon, Thermopylæ, and Salamis, which were almost contemporary with the first victories of Buddha. But while the victories of Miltiades, Leonidas, and Alexander the Great belong to history only, Buddha, the Gina or Victor, as he is called, is still the ruler of the majority of mankind. - - -

I have so far tried to show what Oriental scholarship has done for us in helping us to a right appreciation of the historical development of the human race, beginning on the Asiatic continent and reaching its highest consummation on this small Asiatic peninsula of ours, which we call Europe, nay, on this very spot where we are now assembled, which has truly been called the center of the whole world. It is due to Oriental scholarship that the gray twilight of ancient history has been illuminated as if by the rays of an unsuspected sunrise. We see

* "Sacred Books of the East;" vol. XXIII, p. 184.

continuity and unity of purpose from beginning to end, when before we saw nothing but an undecipherable chaos. With every new discovery that is made, whether in the royal libraries of Babylonia, or in the royal tombs of Egypt, or in the sacred books of Persia and India, the rays of that sunrise are spreading wider and wider, and under its light the ancient history of our race seems to crystallize, and to disclose in the very forms of its crystallization, laws or purposes running through the most distant ages of the world, of which our forefathers had no suspicion. Here it is where Oriental studies appeal, not to specialists only, but to all who see in the history of the human race the supreme problem of all philosophy, a problem which in the future will have to be studied, not as heretofore, by *a priori* reasoning, but chiefly by the light of historical evidence. The Science of Language, the Science of Mythology, the Science of Religion, aye, the Science of Thought, all have assumed a new aspect, chiefly through the discoveries of Oriental scholars, who have placed facts in the place of theories and displayed before us the historical development of the human race as a worthy rival of the development of nature, displayed before our eyes by the genius and patient labors of Darwin. - - -

But, before I conclude, may I be allowed to tax your patience a few minutes longer, and to ask one more question, though I know that many here present are far more competent to return an authoritative answer to it than your president. Is the benefit to be derived from Oriental studies to be confined to a better understanding of the past, to a truer insight into that marvellous drama, the history of the human race in the East and in the West, whether in historic or prehistoric times? May not our Oriental studies call for general sympathy and support, as helping us to a better understanding of the present, nay, of the future also, with regard to the ever-increasing intercourse between the East and the West? Why should so many practical men, so many statesmen, and rulers, and administrators of Eastern countries, have joined our Congress, if they did not expect some important practical advantages from the study of Eastern languages and Eastern literature?

If the old pernicious prejudice of the white man against the black, of the Aryan against the Semitic race, of the Greek against the Barbarian, has been inherited by ourselves, and there are few who can say that they are entirely free from that *damnosa hæreditas*, nothing, I believe, has so powerfully helped to remove, or at least to soften it, as a more widely spread study of Oriental languages and literature.

STONE AGE BASIS FOR ORIENTAL STUDY.*

By Prof. E. B. Tylor, F. R. S.

It seems a suitable introduction to the work of this section to survey broadly the races belonging to the vast Oriental region and to examine the information now available as to the order of their stages of civilization. In the large definition adopted by this Congress, the Oriental world reaches its extreme limits. It embraces the continent of Asia, stretching through Egypt over Africa, and into Europe over Turke, and Greece, while extending in the far East from group to gr p of ocean islands, where Indonesia, Melanesia, Micronesia, and Polynesia lead on to the continent of Australia and its outlier, Tasmania. Immense also is the range of time through which the culture-history of this Oriental region may be, if often but dimly, traced. History illuminates its comparatively later periods. The earlier can only be inferentially reconstructed by comparison of the still representative races and languages, and their remains materially preserved in the soil and intellectually in culture; that is, in the arts, institutions, and beliefs which have lasted on from the ancient world. On the maps which represent the Oriental world, as known to history, we see a band of civilized nations stretching from Egypt through Phenicia, Babylonia, Assyria, Medo-Persia, India, China. This compact culture band is underlaid by traces of former barbarism and geographically skirted by barbaric border-lands, while a savage region is either actually met with beyond these limits, or its former existence inferred inside as well as outside them. In agreement with recognized principles of the development of culture, it may, I think, be taken that the low culture extending widest, represents the earliest platform of culture over the whole region; that an inner but still vast inlying district rose to the barbaric level, and that within this again the higher culture area was formed. Indeed, the terrace-temple of Babylonia, where terraces narrower, but more lofty, rise one above another, seems to my mind a suggestive model of these stages of culture; where the higher degree covers the smaller area.

* Inaugural address of the president of the section of anthropology and mythology, Ninth International Congress of Orientalists, London, September, 1892; *Transactions*, vol. II.

It is to the wide foundation platform of Oriental culture that my remarks to-day specially refer, not from any over-estimation of the importance of this basis, as compared with the higher stages, but because these latter have, with the aid of historical record, become more familiar to the studious world; while as to the lowest and widest Oriental culture level, I have even some new evidence to offer.

The former presence of races of low culture in countries where none now remain is more than by any other symptom proved by the presence in the ground of stone implements and other objects characteristic of low culture among modern savages and barbarians, and doubtless also characteristic in the remote past. Thus the Stone Age is practically identified with the savage and low barbaric periods. Moreover, the usual division of the Stone Age into the later and higher Neolithic or ground stone period, and the earlier and lower Paleolithic or chipped stone period, the evidence for which has been thoroughly threshed out, may here be taken for granted. As to the Paleolithic period, discoveries of the last generation have established the presence of tribes of men over a large part of Europe whose high antiquity is shown by the geological position in which their relics are found in Quaternary gravel-beds and caves, and by their association with that extinct fauna which gives their age the concise name of the Mammoth period. That their stage of culture was that of savage hunters and fishers is obvious from the rude stone implements themselves, and from other objects of more or less Eskimo type, while at the same time, carvings and scratched outlines of animals show an extraordinary sense of art. It has been proved also that the rude tribes, whose existence was argued from their rudely chipped stone instruments, were not confined to Europe. Let us notice their few but important occurrences within our Oriental area.

Egypt, it is important to notice, has yielded implements of well-marked Paleolithic type, a solid basis for its history of culture. They may be traced on into Syria, while the laterite beds of South India, by their similar quartzite implements, testify to the former habitation of the Peninsula by tribes there representing the primitive savage life. In Siberia, where the remains of the mammoth have been preserved so perfectly, I should think that the weapons of coeval man might probably be found in corresponding quantity, but, so far as I know, no thorough quest for them has yet been made..

At the farthest extreme of our Oriental boundary in Tasmania stone implements which must be classed as low Paleolithic in type appear. So remarkable are the characters of these implements and the circumstances of their occurrence, that as they are very scarce in Europe I have placed on the table all the specimens I have been as yet able to obtain. The point I have to draw attention to is that though of rudeness beyond that of the remotest ages known, they remain in use into our own time. It is now more than thirty years since my attention was aroused by seeing a stone implement from Tasmania in the museum of

the Somersetshire Natural History Society at Taunton, which led me to make inquiry at the International Exhibition of 1862 of Dr. Milligan and other representatives of Tasmania. Their answer I printed in 1865, with a comparison with the implements of the Paleolithic age. "The Tasmanians sometimes used for cutting or notching wood a very rude instrument. Eye-witnesses describe how they would pick up a suitable flat stone, knock off chips from one side, partly or all round the edge, and use it without more ado; and there is a specimen corresponding exactly to this description in the Taunton Museum. An implement found in the drift near Clermont would seem to be much like this," (*Early History of Mankind*, p. 195). This, if not the earliest published notice of these Tasmanian implements was one of the earliest; but it will be observed that it did not yet amount to stating that these rude savages used no stone implements except such rudely chipped ones, for it was not yet proved that they did so. This proof was required to bring the Tasmanians into the position where I wish to place them before you now, that of modern savage representatives of the remotely ancient Paleolithic ages. The requisite evidence has since been supplied by the archaeologists and geologists of the Royal Society of Tasmania.

It was not a question merely of studying the make of implements buried in the ground, as the time was not yet past for descriptions by Englishmen who had actually seen how the natives made and used these roughest of human implements. They might be mere fragments picked up or detached by a blow from the rock, but the more artificial tools were much improved upon by skillfully, with another stone, striking off chips along the margin, so as to give a good cutting edge; but this edge-chipping was only done on one side. The natives were never known to grind an edge, nor to fix the chipped stones in any kind of handle. Of this, the accounts of observers who saw the art carried on, and who, one would think, must have been aware if the natives could do anything better, may be taken as good testimony. At any rate it is proof positive that such specimens as are here exhibited are characteristic of the general standard of the Tasmanian implement-maker's art. It is seen by comparison with ordinary Paleolithic implements from the drift-gravels and bone caves that the modern savage was distinctly lower than the ancient. The pick of the Europeans of the Mammoth period, edged and pointed by alternate chipping on both sides, is far superior to anything seen or described in Tasmania. The typical "hatchet" or "tomahawk," as it is sometimes called, of Tasmania, is at most the equivalent of the one-side edged "scraper" of Paleolithic Europe.

Thus it appears that in this far-off corner of the Oriental world Paleolithic man, not even of the highest, had survived within living memory. The question must of course be raised as to whether the low stage of Tasmanian implements may be due to degeneration; but it is difficult,

without altering our conception of human nature, to suppose the rude ancestors of the savages to have habitually edged their chopping-stones on both sides, and given up this for the one-edged flake, for many purposes much less effective. Not less instructive is the fact that the Tasmanians were not known to fix their chopping-stones in any kind of handle, but only to grasp them in their bare hands. What was the practice in this respect among the Europeans of the Mammoth period is not yet quite conclusively known. Some of their tools or weapons were obviously made for grasping in the hand. Others may have been fixed to wooden hafts, though it is hardly proved that they actually were. At any rate, the Tasmanian example warns us not to rely on the argument that to put a handle to a hatchet must have suggested itself naturally to the lowest savages, for it seems not to have suggested itself to Tasmanians. When they saw the European hatchet and how to use it, they "were transported with joy," and took to it at once. If their ancestors, having fixed their chipped stones in withes or boughs, afterwards held them in their naked hands instead, man is a less intelligent animal than other experience of him would warrant. Even if it should prove by further quest that stone implements of higher finish, say equal to the Australian, occur in the ground or were made by the Tasmanians, this would not much alter the inferences as to their culture-history, but would still leave the Tasmanians as a people actually seen in modern times to pursue their life on a Paleolithic footing under circumstances where Neolithic man would have practised his higher art.

We can hardly over-estimate the anthropological importance of this negroid race, whose grievous extirpation so sadly clouds our colonial history. In the light of these facts Paleolithic man ceases to be a mystery, now that we can see the portraits and examine the life of his far Eastern counterpart. They enable us to realize, at least in vague outline, a state of man in geological antiquity which has lasted on into modern life. It is most instructive to examine what the condition of these modern Paleolithic people was in other respects, and the labors of Mr. Ling Roth, who has collected in a single volume ("*The Tasmanians*" London, 1890) almost every scrap of record, puts it before the world in a picture which, considering how much of the evidence comes from uneducated witnesses, is on the whole remarkably consistent. Of savage tribes not in a state of decay, the Tasmanians may be reckoned among the lowest known. Their want of art in stone implement making agreed with their condition as to other weapons and tools. They had no bow and arrow, like that of their Australian neighbors, no throwing-stick to hurl their spears, and their spears, though they seem to have known how to point them with a human bone, were usually long sticks straightened by bending, and the points of which had been thrust into the fire and sharpened. These, and waddies or clubs tolerably shaped, were their weapons of the chase and war. They had not even the rude bark canoe of the Australians, but a canoe-like raft of rolls of

bark. They were string-makers, good plaiters, and basket-makers, and it is noticed that some of their stitches and plaits are familiar in our own basket-work and point-lace. They made fire with the ordinary fire-drill. Their wandering life accounts for the rudeness of their simple huts and wind-shelters of boughs and bark. Mentally, they have been well defined in the following words: "Their intellectual character is low, yet not so inferior as often described. They appeared stupid when addressed on subjects which had no relation to their mode of life, but they were quick and cunning within their own sphere."

Morally, it is not difficult to understand how two kinds of statements are made about them, which seem incompatible, but are not really so. Their inoffensiveness when not ill treated or alarmed or hostile, gave place to sly and rancorous cruelty toward those they regarded as enemies. Their nomad life brought with it the ancient savage custom of abandoning the sick and aged. As nomad hunters they had but the first rudiments of government by the strong man of the tribe; but as usual among such tribes, when war broke out, the authority of a leader or war chief was recognized. The two great tests, language and religion, hardly place the Tasmanians below recognized savage levels. Enough of their language is preserved to show it as simple and scanty, of an agglutinating type, *mi-na*=I, *mi-to*=to me; *pugga-na*=man, *lowa-na*=woman; *timy*=no; *lugga-na*=foot; compounds of these latter, *lowa-timy* (woman-no)=bachelor; *pugga-lugga-na* (black)=man's footstep. The numerals do not go far, but reach to *pugga-na mara*=5, verbally man-one (obviously he held out one hand). There is a proportion of emotional and imitative words, and no doubt it is true, as described, that their sentences depended much on tone and gesture. It would have been most instructive to have had examples of how this was managed, but, unfortunately, here the information fails. The Tasmanian is distinctly a low organized language, but not at all a language belonging to man in what is called "a state of nature." Still less is this the case with the Tasmanian religion, which is a well-marked animism, extending about as high in its development as among other savages. The accounts given by a number of Europeans, of whom some confused white man's ideas with native, require criticism; but the mistakes generally disappear on comparison, and the vocabularies, which show what religious ideas the natives had words for, are an excellent test. It is quite clear that the word *warrawa*=shadow served them to describe the souls of the dead, who became guardian spirits of their friends and hostile ghosts to their enemies, so feared that men would not willingly go out at night; that there was a good land of the dead, with life like this continuing, or that this land came to be identified with England, whence the dead came back as white men; that demon spirits could possess men with epilepsy and other spirits could expel them; that the land and forest swarmed with spirits, among whom is especially mentioned the echo, which they called

kukanna wurrawina=talking shadow. The spirit or god *Rediarapa*, whose name was identified with thunder and lightning, and who was feared accordingly, is vouched for by full evidence; but the deity, "whom they call the good spirit," and who presides over the day, is not to be found in the vocabularies, and collapses on comparison of documents.

Taken all together, there is definiteness in these accounts of a low Stone Age people seen in actual modern existence. How is it that modern savage man should differ so little from man at the highest geological antiquity? The answer seems to be that of possible permanence as well as possible development in culture. Let a tribe arrive at a condition of equilibrium with surrounding nature, its "*milieu environnant*," to use the phrase of Lamarck, in which it can hold its own, this may be a condition which suggests no progress. As there were shells of the Tertiary period indistinguishable from those now living, so there are men. Behind the Paleolithic period lies that undefined past which, whether keeping tribes unchanged under unchanged conditions or changing under changing conditions, has to account for the condition of savage man, which indeed is within a moderate interval of our own. It is a question not of nature, but of degree.

The Oriental area thus presents a basis of man in the Paleolithic stage of culture, relics of which remarkably occur in boundary districts. Let us now examine the Oriental area occupied by traces of the Neolithic stage.

The South Sea Islanders are the best known of high Stone Age peoples. On the continent of Asia history knows of some peoples, the Ichthyophagi of the Beluchistan coast and the aboriginal tribes of China, as still using stone tools or weapons, but for the most part the former use of these is only apparent by the celts and arrow-heads of stone found in the ground, and explained mystically by peoples who have forgotten their real purpose. Hindus still worship a polished celt under a sacred tree as a symbol of Mahadeva, and the Japanese see in the arrow-heads they pick up in the fields the spirit-arrows of storm fights in the sky. Egypt here, as usual, vindicates its place as the museum of culture-development. The flint arrow-heads and ceremonial flint-knives have long been known, and now the researches of Mr. Petrie show Egypt, not in its remotest antiquity, actually emerging from the age of stone into that of copper and bronze, flint-flakes remaining in use for cutting and chipping tools and to arm the reaper's sickle. This is an industrial condition which may remind us of that of Mexico before the Spanish conquest.

This consideration of the Oriental world during the Neolithic or later Stone Age raises a problem which is complementary, and in some respects converse, to that of the development of culture. It leads us to trace the migration of culture from the higher nations into the lower. Even in what is called the unchanging East the culture of the ruder

tribes is far from being (so to speak) their own, so palpably has it been affected by the influence of foreigners of higher and, consequently, more powerful organization, thoughts, and arts. In the present state of anthropology it is particularly desirable to ask the opinions of special students of the great Oriental nations, from Egypt to China, as to what may be called the old trade-routes by which ideas have been carried over the barbaric world. It seems that this carrying has been actively going on within the limits of what is technically known as the Stone Age. Ever since Cook's voyages the Polynesians have stood, and rightly so, as especially representative of the Stone Age. And yet the traces of their communication with cultured Asia are shown by various symptoms. Playing on the jew's-harp and flying kites are the sports of Asiatic nations, but they spread continuously from Asia over Melanesia and Polynesia, where they may have been before the late times in which they find their way into Europe.

Especial interest attaches to the system of the universe prevalent over the South Sea Islands, examined so as to show how far it differs from the simple doctrine of the three worlds, the *triloka* of earth, firmament, hell—a system which, resting on the apparent direct evidence of the senses, belongs everywhere to man in the earliest stages of knowledge. The Polynesian systems I take as so obviously belonging to the borrowed and degenerate forms of the Babylonian planet-system that I think the questions open are merely in which form and by what route they spread over the Pacific Islands. According to the ideas of the Mangaians themselves, the earth they live on is on the top of a vast hollow cocoanut shell, the interior of which is Avaiki, the under-world, into which the sun and moon descend by western openings and rise in the East. Above, the ten heavens of the blessed spirits rise one above the other. Below, the dismal Hades is divided into stages of gloom and decay, down to mere nothingness.

In the New Zealand cosmology, as recorded by Mr. John White in his *Ancient History of the Maori*, we have a system of the same source, only varying in details. Above the flat earth the ten heavens rise in successive strata. The lowest three contain the clouds and storms, and the lake, which by its overflow pours down rain and hail. Above these are seven heavens inhabited by human souls, other spirits, and gods, up to the highest, where Rehua dwells. The counterpart, ten hells, or rather, stages of the under-world, have the four uppermost under Hine-niu-te-po, Great Woman Night, so that it is there that the sun sets. Below are six more dismal regions, in the lowest three of which is the goddess Meru, the lowest of all being called Meto—that is, extinct or putrid.

Now it is plain that the knowledge of astronomy of the Polynesians neither needed nor authorized these schemes of strata above and below, of which they could know nothing; but regarded as degenerate versions of the Babylonian-Greek astronomy, where the orbits of the sun,

moon, and five planets were interpreted as indicating the seven concentric spheres, with others for the fixed stars, the difficulty is met. Even in the Hindu, Buddhist, and Moslem systems of the universe, though derived from this planetary source, the planetary part (all, indeed, that gives the system its value) has long since dropped out of sight, and the spaces the heavenly bodies occupied have been turned to account in complex series of heavens and hells. Both the Indian and Moslem systems may be easily traced into the Indian Archipelago, and it is a last, and I think not unreasonable, step to suppose them spreading over the Pacific Islands. The Mangaian and Maori schemes even bear a closer resemblance to the Hindu than to the Moslem, indicating Indian religions as their carriers.

Thus I close this attempt to lay a Stone Age basis (if I may use the expression) for the study of Oriental civilization. Not attempting here to rise to the Metal Age and to begin the study of the higher stages, to which alone it has been habitual to confine the term civilization, I commend to Oriental scholars the thought (of which it is well never to lose sight) of the humbler and more ancient stages of life which underlie it.

BIOGRAPHICAL SKETCH OF HENRY MILNE-EDWARDS,*

MEMBER OF THE ACADEMY OF SCIENCES.

By M. Berthelot,

Permanent Secretary of the Academy of Sciences.

The learned man whom I present to your attention to-day—Henry Milne-Edwards—is a peculiar and interesting figure among French naturalists, equally distinguished by his origin, by the period to which he belonged, by his discoveries, his system of instruction, the pupils he trained, and by the lasting influence he exercised upon natural history during a long life entirely devoted to science and his country. He filled a great place in our academy and rendered service to zoology and to higher education that will not be forgotten.

His life exhibits many interesting changes. The son of a foreigner, an Englishman, he was eager to be identified with France, furnishing a new proof of that assimilating power which has always been one of the strong points of our nation. This proof was all the more marked that the young Edwards appears to have been at first rich enough not to depend upon any special advantage he might derive from his title to French citizenship. Afterwards, however, to the benefit of mankind and the honor of our country, necessity urged our future brother to the scientific career in which he was to fill so important a position. This was about the first third of the century which is now so near its end. The great founders of modern zoology of the nineteenth century, Cuvier and Geoffrey Saint-Hilaire, had nearly reached the term of their careers. After a struggle, which will long be celebrated in the history of the sciences, Cuvier stood victorious, and his pupils were almost the sole leaders in the line of instruction, following the methods of their master and striving to complete, according to his principles, the framework of a theory which seemed henceforth to be based upon a strong and immovable foundation, with distinct boundary lines, in the permanence of species. The classification founded upon the so-called natural method and supported by observations of comparative anatomy was then considered the ultimate end of zoology.

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Just at this time appeared Milne-Edwards. His Natural History of Crustaceans appeared at first sight to be a simple development of the teachings of Cuvier, but he infused into them an entire order of new and fruitful ideas drawn from physiology which greatly modified the conception of the principle then held—that of the subordination of types. Milne-Edwards placed side by side with this another principle prolific in consequences—that of the division of labor—and it contributed to the inauguration of a great system of studies and theories which shivered the conventional framework of classification, placed in doubt and rendered purely relative that permanence of species—the cornerstone of Cuvier's system—propounded in short the great problems of the origin and progress in evolution of the types of organized beings. If the light is not yet and never can be perfectly clear on the question of origin, it will not lessen the glory of the scientific generations that have followed during the last fifty years, bringing these questions into the foremost rank and breaking the mould of exclusive dogmatism.

Without doubt the sagacious and temperate mind of Milne-Edwards sometimes refused to handle these problems in all their bearings, but no less has he the great and lasting honor of having taken a personal share in their elaboration and of supplying some of their fundamental principles. Silence would be unjust to his memory, and I shall ask permission to express my sentiments later with regard to this work of his, as the time for hesitation is past. Everywhere in the civilized world these questions are continually agitated, and an excess of timidity would enfeeble the authority even of the Academy and French science. However uncertain and obscure they may seem, their interest to philosophy and human destiny is too great for us to refuse to present them here, with the gravity and reservations that respect for truth and the dignity of science demand.

I.—HIS CAREER.

Henry Milne-Edwards was born at Bruges, October 23, 1800. We lost him on the 20th of July, 1885, his long life having been full of work profitable to humanity. He was the twenty-eighth child of William Edwards, planter and colonel of militia at Jamaica. His father was married twice. After leaving the colonies and then residing sometime in England he established himself in Belgium. There our fellow scientist was born, and he took advantage of the place of his birth, at that time part of France, to claim the title of French citizen after 1814. The sympathetic and hospitable genius of France has always known how to gain the affection of foreigners who dwell on her soil, and to associate them by national ties with her own destiny she turns to account the inherent qualities of the races that cultivate her soil and those of neighboring ones, which she has always had the art and energy to assimilate by voluntary attraction. Few acquisitions of this kind have been more fruitful than that of Edwards.

William's love for our country must have been very strong, for it had resisted a severe test, he having been imprisoned by the Imperial police for seven years for aiding in the escape of some Englishmen incarcerated at Bruges. As soon as he was released, in 1814, he went to Paris to live, and reclaimed for his son the benefits of the law which recognized him as a French citizen.

Meanwhile, owing to his captivity, he had not been able to conduct the early education of his son Henry; this was directed by a brother 24 years older, and named William, after his father. This William Edwards also has become prominent among the physiologists of his time. He is one of the founders of the Ethnological Society of Paris, and has left some interesting experiments as a memorial. There is no doubt that by his example and the bent of his mind he exercised a great influence on the vocation of Henry. It is said that the latter, having received as a gift *Buffon's History of Animals*, attempted to analyze it at the age of 11 years, the first indication of that inquiring spirit which at a later period constantly incited his mind to new discoveries.

Reared in ease, married at the age of 23 to an amiable and distinguished lady, Miss Laura Trézel, the daughter of a colonel who after ward became general and minister of war, it would appear that Henry Edwards under such circumstances need never have been called upon to expose himself to danger in the pursuit of the sciences. In the beginning of his career, if he took a diploma as doctor of medicine it was probably in consequence of the same principle by which his father, faithful to the ideas of Rousseau and the eighteenth century, made him learn a manual avocation. Henry lived surrounded by friends of his own age who were well instructed and had inquiring minds like himself. He was then a rich young lover of art, interested in painting, and above all in music, and we know he retained these fine tastes through life, manifesting them in the soirées he gave to men of letters at the museum.

During the first years of the Restoration, the French mind, emerging from the long military repression of the Empire, took a new flight. Everywhere throughout the country and in all departments, intelligent men grouped together to take possession of the domain that was enkindled anew to mental effort and liberty. Whilst William Edwards was more particularly allied with the learned physiologists and anatomists, Béclard, Laennec, Breschet, and Magendie, his brother Henry cultivated the society of physicians and artists. These last he met at the Sorbonne, where the present generation would not be likely to look for such associations.

This ancient refuge of theologians was at that time appropriated to lodgings for artists and sculptors, later transformed into laboratories and dissecting rooms, which our times have in their turn torn down and rebuilt on a grander scale for other educational purposes. Perhaps we may be permitted to cast a parting regret at the old buildings

which for two centuries have sheltered generations animated by a very different spirit, but equally devoted to the culture of the ideal.

There Milne-Edwards enjoyed himself in the society of artists and seemed destined to pass his life in an elegant dilletantism, but fate had decreed otherwise, and the brilliant lover of art was to be tranformed into a savant of the first order. As is usually the case, this was effected by the pressure of necessity: *Duris urgens in rebus egestas*, the transformation took place. In 1825, in consequence of family circumstances, Henry's situation suddenly changed. He was obliged to give up an inheritance that constituted the principal part of his possessions, and to labor for the necessary means of support for his family. The publication of elementary works on medicine and materia medica seems to have at first sufficed. At that time he met with help from the circle of devoted friends he had so well known how to make when he connected himself with distinguished young men like Dumas, Adolphe Brongniart, and Audouin, all of whom before very long became scientific luminaries themselves. They all met later as fellow members in the bosom of our Academy. The friendly aid given to Edwards manifested itself in the line of original research and in his career of instructor.

To speak first of this latter calling, it became to him a real vocation. In 1832 Milne-Edwards was appointed professor of hygiene and natural history in the Central School of Arts and Manufactures, a school over which Dumas, as one of the original founders, exerted a powerful influence. Milne-Edwards had declined the offer of a place in the school system of Belgium during the preceding year, at the time of the establishment of the new kingdom.

For the last time he made a practical use of his medical knowledge in taking care of the sick, through a sentiment of pure devotion, during the great cholera epidemic of 1832. But from that time he turned in another direction, displaying more and more his double talent of professor and writer. At one time he gave a course in natural history at Henry IV College, but only to the junior class. From the close of the year 1837 he no longer taught, as I can certify from my personal recollection as a pupil of that College; his merit and his work called him to a higher sphere. In fact, on the 5th of November, 1838, he was appointed a member of the Academy of Sciences in the zoological section, to replace Frederick Cuvier, and in 1841 succeeded his friend, Victor Audouin, in the chair of entomology at the museum, which he exchanged in 1861 for that of mammology. In 1844 he added to this the title of chairman of the "Faculté des Sciences," which he had filled as substitute since 1838, and his well-known spirit of order and justice caused him to be chosen dean in 1849; he filled the double offices of professor and dean at the Sorbonne up to the last day of his life, having faithfully discharged his public and private duties with great activity, without a break, and rarely ever so much as requiring

a substitute. Recall that to complete his *cursum honorum* he was made chevalier of the Legion of Honor in 1834, and grand officer in his old age; that he belonged to the Royal Society of London, to the Academies of St. Petersburg, Berlin, Vienna, Brussels, Boston, Philadelphia, etc., in brief, to most of the great societies of learned men. Honors of every kind, some of them official, others more precious, coming from savants his peers in different parts of the world, were continually bestowed upon him, and day after day crowned this long life which had been consecrated to the search for truth.

His private life was not always so happy; it was marked by more than one of those painful crises from which no man can be exempt.

I have told you the first difficulties he encountered from a material point of view, and how these difficulties only gave a greater impetus and energy to the scientific education of our fellow-worker. What happy hours he enjoyed when, refreshing himself from his daily labors in holiday excursions, he dedicated his journeys to Granville, the Chausey Isles, St. Malo, Cancale, and Mount St. Michel, to original studies of marine animals in their native habitat on the seashore, making his observations direct from nature, dissecting fresh animals and sketching them with an accurate and skillful hand.

These labors were accomplished with all the more enthusiasm that they were undertaken with his friend Audouin, both of them young, ardent, and accompanied by devoted wives who had no other ideals than their husbands, and who sketched and painted in water colors the animals that were captured each day. The *Annals of Natural Sciences* have preserved the record of this double collaboration by giving a place to their most interesting works on crustaceans, annelids, ascidians, polyps, and various zoophytes.

Milne Edwards had already explored the coast of Provence and Italy, and in 1834, through his connection with General Trézel he was enabled to extend his investigations to Algiers.

This domestic felicity was soon to become clouded by sorrow. More than half of his ten children died at an early age. Though he had the happiness of seeing his son Alphonse—first his pupil, then his competitor—succeed him at the museum, and become a fellow member of the Academy, and though his daughters, who married, successively, the son of Dumas, gave him the satisfaction of seeing heirs to two illustrious names grow up around him, still his life was saddened by the ill health of his beloved wife, the partner of his struggles and successes for twenty years. In 1839 she was attacked by a serious lung trouble, which proved fatal at the close of three years in spite of the tender care lavished upon her by her devoted husband.

He sought consolation in his work and in the friendship of the young savants around him whose studies he directed. Quatrefages, Blanchard, Lacaze-Duthiers, Marion, and many others, can bear witness to his sympathy for youth and his constant and zealous encouragement.

If Milne-Edwards does not display the fervor of language and boldness of theory of some of his contemporaries, such as Blainville, none the less he roused a spirit of inquiry in his hearers, without which there can be no really original research and an enthusiasm which sustains the inquirer amidst the obscurities and disappointments of patient investigation.

He made a tour of Sicily in 1844, in company with Quatrefages and Blanchard, that has become celebrated in the history of zoology. He did not hesitate to go down into the sea to a depth of 8 meters, by means of a diving apparatus, in order to study the life of marine animals. This practice has now become customary at Roscoff's laboratory, under the direction of our co-worker, Lacaze-Duthiers, and the soundings of the *Talisman* revealed many other mysteries to Alphonse Milne-Edwards; but fifty years ago it was venturesome to take the initiative, the apparatus being less perfect, the use of it less understood, and it required considerable courage for a scientist to bury himself in this fashion for the first time in the depths of the sea in order to wrest from it the secrets of life.

At the same time, in the course of his daily life at Paris, Milne-Edwards made his home at the museum a center for learned men, gathering them around him in social evening reunions which are still remembered by my contemporaries. One was sure of meeting there the highest order of men, both Frenchmen and foreigners. Englishmen, attracted by a common nationality, or at least ancestry, came willingly, and we listened with respect to these men so devoted to science, an honor to their country; they were living models of the profession to which each of us intended to dedicate our lives. In the midst of this group the refined, pleasing figure of Milne-Edwards was always seen moving from one to another, ready to show his sympathy with each by an appropriate word to the young as well as the old, and to express his opinion, nearly always a characteristic one, in the scientific discussions going on around him.

This social and stirring life which he enjoyed, was interrupted in 1856 by a serious affection of the stomach. Milne-Edwards had all his life suffered from a delicate constitution struggling to resist disease. It was thought at first that the crisis of this illness would be fatal. I can still recall that face, sallow from jaundice, the eyes bright with the fire of intellectual life.

He at length partially triumphed over illness, it might be said by the strength of his will power. Not only did he refuse to submit to disease, but at this very time undertook the editing of his great work on comparative physiology and anatomy which was to occupy him for twenty-five years. What a forcible example of mental power, proving that man should never despair, however great the perils and tests of material or moral life!

Meanwhile Milne-Edwards continued in the service of science and

in the career of teacher. At the museum, as at the Sorbonne, everywhere, this little man was to be seen, firm, benevolent, always conversant with the least detail, whether administrative or scientific, ever ready to practice what he preached. Those who knew him in the council board of the University will not forget his kindly interest in watching the development of young scholars; they remember those note books, those special memoranda of their work and standing that he filed each day so conscientiously. He had in the highest degree the sentiment and love of the good.

In this way he left his impress on the history of the "Faculté des Sciences," at Paris, and aided in the revolution effected in the last twenty years, as well as in the entire system of higher instruction; both have been re-constructed under an impulse which more than one of my listeners has contributed to give by his support and devotion. I would cite as an example of the pioneer efforts of Milne-Edwards those scholarships for students which have proved so fruitful in the encouragement of youthful talent in our public educational institutions. He started this system in 1849 by means of limited assistance, which was withdrawn, owing to the violent reaction of that period, but was continued on a larger scale thirty years later through the liberality of the republican government.

Of a different but not less useful class, the scientific excursions of Milne-Edwards and his pupils to the sea-shore were the prelude to the creation of those stations of marine zoology now encircling our coast, like a crown of honor, through the zeal of such men as Lacaze-Duthiers, Pouchet, Bert, Sabatier, Marion, and Giard, foreign workers speedily following their example.

Milne-Edwards, belonging essentially to the scientific class, never extended his services and authority to the arena of politics. He was ready however to perform in a manly way the duties of a citizen in any emergency. When the gloomy days of the siege of Paris came, and the city was surrounded by the enemy, Milne-Edwards, already afflicted by the loss of one of his sons-in-law, who had been killed at Gravelotte, nevertheless brought to the national defense a patrotic band of learned men, whose unanimity of sentiment and action will redound in history to the honor of French science and the Academy.

When the shells were crashing against the museum he remained at his post, going back and forth from the Jardin des Plantes night and day to provide as quickly as possible for every contingency. There came a day still more distressing, when he had to go to Fort Bicetre and look for young Desnoyers, the son of a devoted friend, who had been mortally wounded, and he himself held the reins and led the ambulance along a road whereon the enemy's shells were raining fast.

Such are the incidents that have diversified the lives of the men of our day, not less troubled, perhaps, than were the savants of the sixteenth century from foreign and civil wars.

Peace re-established, he resumed his course of instruction and the publication of his great work. When the work was finished a well-earned joy and reward awaited him; his scholars, friends and admirers, under the leadership of M. de Quatrefages, presented him with a medal of honor. Milne-Edwards was then an octogenarian, crowned with honor and years; he had made his literary debut in 1823, nearly sixty years back, and, continuing his labors for half a century, awaited the end of his mortal life with the serenity of a wise man, offering us this beautiful example of a career that was active and useful to the last, thus showing that the constant exercise of the intellectual powers, instead of exhausting a man, sustains him beyond the common term of years, and preserves him from decay by continually bringing his faculties into play in the strict fulfilment of daily duties. He also died, like the Roman emperor, repeating that noble word, *Laboremus*.

II.—HIS SCIENTIFIC WORK.

The time has come to examine the scientific work of Milne-Edwards. He was at the head of the French School of Natural History for many years. The greater number of the scientists constituting that body to-day were his pupils. It is necessary, then, to pass in review his special works and those that in conjunction with this organization had established his reputation, also to note his share in the scientific movement of his times and the general theories he supported, without suppressing the gaps in certain directions, due to his spirit of precision in practical matters, and perhaps to a kind of theoretical timidity that characterized his conclusions.

I will speak first of his special work. It was chiefly directed to the study of marine animals, crustaceans, annelids, mollusks, and zoophytes. This work, undertaken at the start in collaboration with Audouin, was afterward pursued alone by Milne-Edwards, giving the impulse to a vast series of zoological studies that have extended to our day with a fecundity inexhaustible as life itself. Up to that time it was the custom to study principally dead animals, dried or preserved in alcohol. The inconvenience of this mode was perhaps less with terrestrial animals, their shape being better defined and less affected by the great difference of density of their habitat. Marine organisms are otherwise affected; their tissue and their organs, sustained during life by the water in which they are submerged and scarcely differing from it in density, are subject after death to great variations of form and dimension. Up to that time there had also been a preference for the morphological study of the hard parts or skeletons, such as the shells of mollusks, the carapaces of crustaceans, the solid supports of radiates. The interior organs, it is true, had been carefully examined after the method of Cuvier, but this had been done with subjects preserved in liquids, which distorted them, contracting and changing the greater part of their tissues, not to speak of the dissolvent action of the liquids upon

certain products. All these objects remained little understood, and the functions of their organs were still more obscure. Thus a new order revealed itself when naturalists—Milne-Edwards, one of the first—began to study marine organisms no longer in collections but in their own habitat in the bosom of the sea, even in the active conditions of their existence. This new class of study marked one of the characteristic features of the work of Milne-Edwards, and of those following him of the French school—I mean to say this intimate and consistent union of physiology with anatomy. Science has been re-created, owing to the gradual ascendancy of the points of view revealed by this union over questions of simple classification that had hitherto been dominant under the influence of Linnæus, de Jussieu, and Cuvier.

In 1827 Milne-Edwards published conjointly with Audouin his "Anatomical and Physiological Investigations of the Circulation of Crustaceans," investigations that made a sensation and in 1828 gained the Academy's prize for experimental physiology. Studies on the respiration of crustaceans and on the branchial modifications for the purpose of adapting crustaceans to life on the earth, investigations of the nervous and muscular systems of crustaceans, their geographical distribuion being regulated, according to this author, by the double consideration of the existence of several distinct centers of creation and by the unequal fitness of species for swimming, combined with purely physical conditions of temperature. The nearer we approach the equator the more varied and more highly organized species become.

The investigations of the organization and classification of decapoda crustaceans that Milne-Edwards had been making from the year 1831 served as a prelude to a more extensive work—his Natural History of Crustaceans—of which I will presently speak. In 1851 he again took up the interesting morphology of these same decapodal crustaceans.

The study of annelids naturally accompanies that of crustaceans; the greater part have the same habits and often even serve them for prey. From 1829 Milne-Edwards and Audouin were also engaged in describing the species that inhabit the coast of France and in reforming their classification. In 1837 Milne-Edwards was engaged in examining the structure and functions of the circulatory system of annelids. In 1845 he returned to the study of myrianids and he described the mode of multiplication of these singular organisms, showing how their penultimate ring is developed and divided into several distinct rings, constituting a new animal which for a certain time remains united to its parent before separating from it to lead an independent existence. Often, even before this separation takes place, it becomes in its own turn the point of departure of a similar section and for the production of a third organism like itself and its progenitor, and so on; so that in this way as many as six young ones attached in a series may be seen at the posterior extremity of the parent individual or stock which serves as common ancestor.

Between the years of 1826 and 1845 the history of mollusks, and especially that of ascidians, equally owe important contributions to Milne-Edwards. He particularly observed the circulation of these animals, which is more perfect and better developed than that of insects, and exhibits in some cases a remarkable peculiarity. Their blood does not only flow in vessels with partitions strictly limited by special membranes, but continues to flow on into a system of openings placed between the different organs in which the alimentary juices mingle directly with the mass of nutritive fluid. De Quatrefages pursued the same system of observations in works which it is not my present province to criticise with respect to their individual character and originality. A great discussion speedily took place between Tereboullet and other learned men on the question of "phlebenterism," the name Quatrefages gave to his discovery, and the result was important modifications in the theories accepted up to that time as to the true character of the circulation and nutrition of the lower animals.

Zoophytes could not escape the new method inaugurated by the investigation of marine organisms. After starting with experiments on polyps, sea mats, and sponges, Milne-Edwards resumed his studies more thoroughly in 1833, 1835, and 1837. He first examined jelly-fish, hitherto regarded as a sort of gelatinous, nearly amorphous mass; in reality, their structure is one of the most complicated, their translucense preventing, at first sight at least, the multiplied details of their organization from being distinguished.

In his investigations of alcyonaria on the coast of Algiers this learned naturalist made apparent the singular structure of those polypiers, which contain both the organs belonging to the young individuals that are placed at the terminal surface and the collective organs which exist only for the benefit of the community, but communicate with the digestive centers of the individuals in such a manner that all profit by the nourishment absorbed by each, thus establishing a common circulatory system between the individuals of one colony. So diverse are modes of life that it is difficult to assign varied organizations to one systematic formula. By his studies of the anatomy of coral in 1838, and above all by his observations of the nature of coral reefs, Milne-Edwards paved the way for the admirable works which were the foundation of the reputation of our colleague, Lacaze-Duthiers.

But I must pause in this long enumeration of the special labors of Milne-Edwards to take them up as a whole, to analyze them, and show their historical share and importance in the development of the natural sciences; for this a longer time would be required than I have at my disposal to-day, and, I do not hesitate to say, a voice having more authority. However I can not pass by in silence two books which attracted the attention of their time by reason of entirely distinct claims. I will speak first of the works relating to the production of beeswax. A great dispute had arisen between agricultural chemists about

the origin of the fat of animals, a dispute connected with a question of more extended bearing—that of the origin itself of the direct principles of human beings. Some thought that vegetables alone make fatty matter; that introduced by food into the bodies of herbivorous animals, it then passes into the tissues of those animals which are powerless of themselves to form it. Such was the opinion entertained in the discussion by the greater part of intelligent minds, especially by Boussingault, justly considered an authority on these questions. Others, Liebig in particular, thought on the contrary that the fundamental chemical agencies which govern production of the direct principles have the same source in vegetables and animals, and they advanced in support of this theory several proofs carefully deduced from the production of fatty substances. But these proofs were indirect and were deemed insufficient by their opponents. A long controversy ensued; it was cut short, but not by the study of the agencies which engender fatty substances—agencies still unknown. The definite result of the process however may be known by determining the relative weight of fatty substances contained in the organism and in the food of mammals and birds in various periods of their existence, particularly in the conditions of fattening domestic animals.

Milne-Edwards, associated with Dumas, made an ingenious and delicate demonstration as a result of his study of insects. This related to the production of the honey which bees manufacture so abundantly. Determining by comparison the quantity of fatty matter that pre-exists in the bodies of bees—a quantity relatively minute—and by feeding a hive exclusively with the sugar necessary to the fabrication of their honeycombs, the authors established as a fact that wax is made at the expense of the saccharine element; that is to say, without the aid of a fatty substance furnished by alimentation. The test was exact; added to others made in various places, it carried conviction to all, even to its opponents.

There is another book of Milne-Edwards that should be taken up as a proof of the superior tendency of his mind; this work belongs to the early period of his career when he was dividing his energies between his medical vocation and his scientific studies. This was a publication made in 1829, in company with the philanthropic political economist, Villermé, and related to the influence of temperature upon the mortality of newly-born infants. The authors showed how these infants are exposed to danger under the influence of variations of temperature, especially of cold, their organs being as yet unaccustomed to react against the surrounding medium. Now the rules relating to obligatory presentation of newly-born infants before the officer of the civil government, as well as to their baptism in church, expose them to a chill dangerous in proportion to the low degree of the outside temperature. The authors proved this to be cause of mortality, by statistics compiled at different seasons and in distinct localities, and demanded a reform of

these murderous laws and the substitution of an authorized certificate for the actual presence of the infant. Their opinion was founded upon unanswerable proofs, but it is not easy to contend against the routine of established custom. This reform did not take place, still another generation was needed to receive it with tolerance; it is only in our day that the principle at stake has been definitely acknowledged.

III.—HIS THEORETICAL VIEWS.

Enough notice has been given to the books and special work of Milne Edwards. Surely the original and special studies of a learned man are the necessary basis of his work, and it is principally by means of such that he acquires authority. However, these do not constitute his entire work, and often not the essential part of it. This last rests rather upon the labors accomplished as a whole by the author, by uniting his individual work with the bearing of the general ideas and theories he promoted. This confirmation is not wanting to Milne-Edwards. From the beginning of his career he wrote treatises on the diffusion of knowledge among the people, specially useful in lines of instruction that set forth the views and natural laws for which his name still stands.

These views were principally developed in works of a more original character that still remain to science, such as the Natural History of Crustaceans, which comprises this order as a whole, uniting and co-ordinating the results of the first part of his scientific career; the Introduction to General Zoology, and Lessons on the Physiology and Comparative Anatomy of Man and Animals, a vast encyclopedia of nature in fourteen volumes, setting forth the labors of his contemporaries and treating the general systems that have held a place in the science of the nineteenth century.

The Natural History of Crustaceans, was written in the first years of the reign of Louis Philippe, a short time after the death of Cuvier, and under the inspiration of the lively disputes that had first taken place between him and Geoffry Saint-Hilaire with regard to the unity and correlation of organic systems in animal species. Milne-Edwards contributed his quota of new facts and original views to these theories of natural philosophy. He held to the anatomical structure of the tegumentary skeleton of a great zoological type—the crustaceans—a skeleton having homologous parts that fulfil the most opposite functions, locomotion, prehension, mastication, sight, touch, respiration, generation, etc. According to him the body of the crustacean type is composed of twenty-one zoonites or elementary animals, associated so as to constitute the animal as a whole; each of these zoonites, supported by a special stem that is connected with the solid framework or dermo-skeleton and constitutes a central ring with parts hanging to it, thus forming a double series of members. If the zoonites always resembled each other we would have a uniform organism repeating

itself in every part like a myriapod, but this conformity may vary from different causes so as to constitute a multiplication of types. In certain families it happens sometimes that one or more of the zoonites failing to perfect normally causes important modifications of form and structure in the others of the same family, and consequently among neighboring zoonites. Sometimes the adjacent rings weld and mingle together, this blending remaining marked by the persistence of certain grooves or lines of less resistance; some among them lose at a certain period the organs that existed at an earlier stage of life. In this way the caudal fin of young crabs disappears in the adult. Crustaceans of the parasitic order present in this respect the strangest suppressions and malformations, retaining at the end of a certain period only the organs of nutrition that are necessary to their particular kind of life; in compensation, also, sometimes becoming enormously developed. These abortions, arrests of development, and atrophied parts not only appear among the zoonites but also in their anatomical elements themselves. In fact each zoonite in turn is formed of several distinct parts or sclerodermites, which also, by welding together, produce arrests of development and atrophied members. In opposition to this it is observed that the determinate part has an excessive development and a relative preponderance, for, increasing in size, it extends and trespasses upon neighboring parts. It multiplies itself, sometimes by a simple repetition, sometimes by a redoubling, so to speak, of its typical parts. But nature does not limit herself to a single process to attain her end. It may also happen that this preponderating element grows by a general development that is simultaneous and uniform throughout the different parts. Thus there is an indefinite variety of natural combinations, all remaining subject to the limits of one same fundamental type and to a kind of economy in processes and modified elements. Crustaceans and marine animals of the lower orders in general offer a most suggestive spectacle of these phenomena to the philosophic mind.

Nothing is more interesting than to survey, with Milne-Edwards, this extensive, at the same time homogeneous, group of crustaceans. From them may be learned not only the form and the nature of organs but the way these organs act; in other words, the study of structure is always intimately connected with that of function and its offices. This method is an innovation upon Cuvier's, which was to distribute the animal kingdom strictly according to its organization—that is to say, its anatomy.

Milne-Edwards to a wonderful degree extended the limits of the zoology of his time by introducing physiology as an essential part. This was an original characteristic and one of the consequences of the new method of study that he inaugurated in examining marine animals in their own place and in a living state.

The examination of the lower animals offers immense resources in

this respect that had not been understood when naturalists devoted themselves chiefly to the study of vertebrates, the organic structure of which is usually distinct and specialized as to functions. In the lower orders offices become more and more simplified, the common organ has multiple functions, the essential character of these functions tending to manifest itself more radically.

While Milne-Edwards was pursuing his original investigations the character of his professorship at the "Faculte des Sciences" led him to embrace the whole animal kingdom in his range, and he kept in constant touch with the fresh discoveries of zoologists. He thought it expedient to build upon his private notes a more enduring work that would represent his method of instruction in a more definite manner. To this feeling was due the conception of his great work, *Lessons on the Physiology and Comparative Anatomy of Man and Animals* which does the highest honor to his conscientious methods and to the scope of his intellect. The publication of this book continued in fourteen volumes, over a term of twenty-four years, through critical periods in Milne-Edward's personal health as well as in French society.

In this masterwork the author approaches first the study of all organized systems destined to divers functions in the animal chain. He proceeds to follow a method of historical and progressive explanation that is full of interest and worthy to exemplify the march of the human mind in the search for truth. Studying every organized system, Milne-Edwards shows their innumerable transformations and the progress or degradation of organization among general types according to the relative importance of the function to which the class is destined; in short, he shows its adaptation to the varied conditions of existence. In this connection he treats successively the great problems offered by the study of life, its origin, and its manifestations; problems that perhaps no century has more incessantly and deeply agitated than our own. Milne-Edwards might be reproached for a want of boldness sometimes in the discussion of these great questions, his wise and prudent mind preferring to lend itself to the solution of lesser ones. It is certain that he did not refuse to recognize the evidence of facts and of their relation to origin revealed to us by geology; but he would not engage in the conjectural line of systems and theories by which the attempt has been made to explain the descent of animals. While recognizing the fact that living animals are derived from animals that lived in the geological periods, he was prompt to add that we could not account for the production of organisms capable of presenting a form specifically new and suited for transmission to their progeny. If he declares in fitting terms that he "could not connect himself with those who represent the Deity as moulding brute matter with his hands in order to give form to a preconceived idea of one organized being or another, and breathing into this still inert machine the principle of life," to balance this statement he also adds that the known properties

of matter, whether inert or active, seems to him insufficient to give such a result, and that the intervention of a superior power to him appears necessary. To sum up all, he remains loyal to the old conception which regards life as "an organizing force of ponderable matter," and the organization of the living being not the cause of the vital power it posseses, but, on the contrary, a consequence of the properties of that force.

Milne-Edwards did not take up these new views of our time. To use a comparison often made since the days of the ancient poets, the evolution of life was likened to a permanent flame, according to the theory of a purely kinematic creation by a system of co-ordinated impulses, centralized in some one direction by merely mechanical conditions, and sustained by a consummation of energy independent even of that direction. To this conception, founded on facts borrowed exclusively from the physical and material world and tending to regard the individuality of every human being as an illusion and man himself the simple result of his organic construction, philosophers given to the study of the moral world oppose another and an apparently contradictory conception, which, founded on the existence of conscience, regards the psychological individual as primordial and the exterior world as determined by his own thoughts, having no intelligible existence outside of his mind. Between these contradictory views and methods I can not decide here; this is not the place to insist upon the solution of problems that must long, if not forever, remain veiled to the weakness of the human understanding. Let us however guard against declining to investigate or refusing even to voice such questions, either from the side of mysticism, which would deny the fundamental object of all science, or from the side of the professed skepticism, which to-day threatens to overtake so many wearied minds.

Whatever may be said and thought in regard to this subject, it was not these tremendous questions that our learned brother preferred to spend his time in considering, it was not upon these that he left his mark. Such was not the design of a work that was based upon the research of other men. A book of reference, with whatever ability it may be compiled, requires a certain sentiment of sacrifice and self-abnegation on the part of its author; if he renders the greatest services to the present generation in the necessary course of years he seldom escapes finding his work incomplete and old fashioned. During the long series of years dedicated to its publication science undergoes various changes, that become still more accentuated as earlier impressions give way to others in the lapse of time. This is inevitable by reason of the ever-increasing number of workers, the diversity of languages and nations, each looking at science from the point of view most nearly conformed to its own genius and traditions. Besides, this individuality is more aggressive than it was formerly. A man after becoming learned and familiar with methods would often rather acknowledge

his indebtedness to them than enroll himself under the banner of a master. By reason of these manifold circumstances a book of a general character, a compilation with whatever care it may have been prepared, will seldom live beyond the generation for which it was compiled; sooner or later it will be replaced by one of the same kind more in touch with the works of the day and itself destined to a transient fame.

IV.—HIS ZOOLOGICAL PHILOSOPHY.

It is better to dwell upon the individual and original ideas of Milne-Edwards that will remain associated with his name and to which he has given definite and lasting expression, if, indeed, any theory can lay claim to such a character in the incessant changes and revolutions of human knowledge. Milne-Edwards, in fact, had been led by his indefatigable labors and his ever improving methods of instruction to explain certain general theories respecting the agencies which control the innumerable metamorphoses of organs and their correlative functions. He took up these theories again in one of the most remarkable of his smaller books, published in 1858, under the title of "An Introduction to General Zoology, or Notes on the Tendencies of Nature in the Constitution of the Animal Kingdom."

This title itself is characteristic of the man and of his times. In fact, nature is now rarely spoken of as if it were regarded in the light of an actual personality having a character, tendencies, and caprices after the fashion of a moral being. Whether right or wrong, language implying that nature is a working machine has been substituted for these sentimental expressions, but at bottom these later ideas have no less significance. In reality, whatever the language used, the question in point is always to examine and ascertain the same essential relations between organic systems and functions; facts flow out of these relations, or, as I might say, out of the investigation of living beings and the phenomena of which they are the seat. Only instead of seeking to discover in them a pre-conceived design for some special and often puerile purpose, the scientist recognizes with admiration the harmony and general co-ordination in the permanent regularity of natural laws, the condition of the persistence of human beings, alike as individual types and as successive generations.

One of the simplest and most interesting of these necessary relations was discovered by Milne-Edwards, who traced its consequences with wonderful quickness of perception. This was the principle of the division of labor, which he first observed in his studies of crustaceans to operate both in the development of the types of animal species and in the perfecting of those types.

To start from this point of departure, two laws, according to Milne-Edwards, are discoverable in animal organisms: a tendency to variation, or the law of change, and the law of economy by virtue of which this variation takes place in each type within given limits, exhaust-

ing all the combinations comprised in those limits. But the variations themselves are not produced by chance,—and just at this point this author begins to present original views,—they take place through a principle similar to that which governs the mechanical industry and organization of human societies, the principle of the division of labor. This is in a manner borrowed by political economy.

When human societies are in their primitive stage each man is obliged to provide for his separate needs, he must procure his food, construct his dwelling, manufacture his clothing and all objects necessary to his life, health, and personal defense. Among civilized peoples, on the contrary, each member of the association devotes himself to the accomplishment of a fixed portion of this labor, but he performs this with a greater degree of economy and perfection; thus the social machine becomes co-ordinated and hierarchical while being perfected.

To carry these ideas into the animal order every living creature is fitted to procure food and to reproduce its kind, these fundamental functions being common to vegetables and animals. The distinctive feature of the latter is that they are capable of feeling and of motion, these functions being fulfilled in a way that leads to the persistence of the individual and of the species; it may be said that every animal is absolutely perfect. The human mind however conceives of different degrees in this perfection. At the foot of the ladder we perceive animals like sponges and certain zoophytes constituting a mass of uniform appearance qualified for the same functions throughout all the parts, while performing apparently automatic movements. The same tissue seizes the food to be digested, contracts, dilates, breathes at the expense of the surrounding watery medium, appears to be affected by the sensations of light and heat, is multiplied and reproduced in the case of spontaneous or accidental fracture. A hydroid polyp may be cut in pieces and each separate piece will be capable of carrying on without change an individual existence similar to that of the original body. By this it will be seen that the function existed before the organ; far from being the product of the organ it serves to fit it for a special purpose. In fact, by the side of these simple animals, such as sponges or hydroid polyps, we meet with others in which each function begins to be set apart for special purposes. Digestion is performed in special cavities, generation is effected in a distinct manner; circulation, respiration, power of motion, all the sensations acquire in succession their proper working apparatus, to be in turn divided into different parts that are destined to the performance of one of the acts of which the whole constitutes the general function.

Thus digestion first taking place in an interior cavity provided with a tissue similar to that which constitutes the general surface of the body, soon acquires a special cavity, a stomach at first adventitious and temporary, but becoming permanent in other species. In proportion as the scale of life ascends the animal is at the proper time pro-

vided with orifices for receiving nourishment and for throwing off waste matter, also with fixed conditions of life and a definite form. Next, the digestive apparatus is divided into several regions, one designed for the introduction of food, another for its chemical operations, and still another for the absorption of nutritive juices. The form of each of these regions is again subdivided, prehensile organs are seen to appear employed for seizing prey, other organs employed in sharing and submitting it to a preliminary mechanical preparation. Special glands are observed that manufacture chemical agents designed to effect changes in the various kinds of food. In other cases the transportation of digested material instead of being effected by contact and by means of diffusion among the tissues, gives place to a new apparatus which carries them thoughout—this is the vascular system—and by virtue of a growing specialization it develops a double current for distributing the fluids even to the most remote organs, where they give up their nutritive elements, and are brought back to the center to again resume their first office; from this process the vessels and the heart result, which again separate into different parts, each performing a distinct act.

In this may be observed all the applications of the new principle and its influence upon the division of organic labor as distributed into multiplied functions, each one performed by a suitable apparatus resulting from the specialized development of one part or another, henceforth to be set apart for one sole purpose, whilst it becomes insufficient if not absolutely useless for all other purposes. It must be understood in addition to this that this partial function remains necessarily co-ordinated with other functions in the general physiological action of which it performs one part, that is to say, that the complete system while centralizing more and more always as a whole, becomes particularized into special organs.

The result of this provision is work better done and continually perfected, so that as a result of the principle of the division of labor we have the perfecting of particular organs for a special purpose, along with the elevation of the general animal type and of the part it plays in the order of nature.

Advancing still further, the principle of the division of labor enables us to reach the heart itself of zoological philosophy. From the moment that the organ does not create the function, but is on the contrary modified and adapted by it, from the point of view of classification the form and even the existence of the organ do not assume the arbitrary significance it was formerly deemed necessary to attribute to them; it it is no longer permissible to speak of established and preponderating types. On the contrary the zoological significance of one anatomical type varies continually in passing from one group of animals to another. It varies even in similar parts of the same animal, according to the diverse functions the organ is called upon to perform.

We see from this how the new principle, slightly vague at the first glance, acquires an ever-increasing clearness and importance by reason of its chain of deductions. The applications that may be made of this far-reaching principle are innumerable and infinitely varied; it may be said it controls the entire catalogue of animal life.

We must not forget that this progress is often relative. If mollusks have a general superiority over insects because of their digestive apparatus and circulation, they are on the contrary inferior in their organs of locomotion and the activity of their life in general. In a higher order, if man is superior in intelligence to the dog, he has less highly developed olfactory organs; his sense of sight is also equally inferior to that of most birds.

Other examples still might be given. In fact, we have likened the principle of the division of labor in animal organisms to that which takes place in the history of humanity. But if we compare societies of animals to human societies we will see that the functional division of social work is often carried to a greater extent among the former than among men. Among ants and bees the work of reproduction of the species is distinct from the work of maintaining the colony. Certain individuals, sometimes one only, are set aside for the generative office. There is only one female in a hive of bees, while the colony is fed and supported by the activity of the working bees that have become sterile by the atrophy of the organs of generation. To a systematic mind this feature of animal societies would seem to be a mark of superiority, but I shall not insist upon this claim. I have only wished to show the relation the progress of the lower animals bears to our own, and the analogies that exist in certain respects.

Whatever these analogies may be they add nothing to the importance of the principle of the division of labor, and the interest of the general deductions flowing therefrom. It is greatly to the honor of Milne-Edwards that he has shown the full bearing of this principle, and followed up its application with a keenness of perception, method of logic, and force of deduction that are incomparable. However extensive the work of a learned man may be, whatever personal authority he may derive from his times, his name rests with posterity only on what it stands for, whether this be the discovery or explanation of some remarkable fact, or the demonstration of a general theory and its bearing upon a science as a whole. This latter claim Milne-Edwards had the good fortune, the talent, and the lasting glory to establish, and in consequence his name will remain among those of the leading naturalists of the nineteenth century.

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